(12) MR 82-5

AD A121557

Floating Breakwater Field Experience, West Coast

by

Eugene P. Richey

MISCELLANEOUS REPORT NO. 82-5

JULY 1982

Approved for public release; distribution unlimited.

NOV 18 1982

A

Prepared for

U.S. ARMY, CORPS OF ENGINEERS

COASTAL ENGINEERING RESEARCH CENTER

Kingman Building

Fort Belvoir, Va. 22060

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MR 82-5	2. GOVT ACCESSION NO. AD-A122 557	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FLOATING BREAKWATER FIELD EXPERIENCE, WEST COAST		5. TYPE OF REPORT & PERIOD COVERED Miscellaneous Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Eugene P. Richey		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Civil Engineering University of Washington Seattle, Washington		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D31679
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Army Coastal Engineering Research Center (CERRE-CS) Kingman Building, Fort Belvoir, Virginia 22060		12. REPORT DATE July 1982
		13. NUMBER OF PAGES 64
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Field evaluation Performance Floating breakwaters

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Existing literature on floating breakwaters is lacking field information on the construction and subsequent performance of these structures. This report partially addresses this deficiency by evaluating 11 existing floating breakwaters located in the Pacific Northwest. The breakwaters consist of five concrete caisson units, three Alaskan-catamaran or ladder-type breakwaters constructed of posttensioned concrete segments, one constructed of surplus oil pipeline sections, one Goodyear floating-tire module breakwater, and one with units consisting of four rows of plastic pontoons. The report includes a description of each site and breakwater structure, a discussion of the breakwater's performance based on site inspections and discussions with owners, marina operators, etc., and a set of conclusions for the overall evaluation of the structures.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

This report is published to provide coastal engineers recent field experience with the design and construction of floating breakwaters on the west coast of the United States. A similar report will be published on field experience with floating breakwaters on the east coast; both reports should provide practical guidance for coastal engineers. The work was carried out under the U.S. Army Coastal Engineering Research Center's (CERC) Design of Floating Breakwaters work unit, Coastal Structure Evaluation and Design Program, Coastal Engineering Area of Civil Works Research and Development.

The report was prepared by Professor Eugene P. Richey, Department of Civil Engineering, University of Washington, Seattle, Washington, under contract with the U.S. Army Engineer District, Seattle. J W. Heavner, Graduate Student, Department of Civil Engineering, University of Washington, assisted with field surveys and data collection.

W.N. Seelig was the CERC monitor for this effort, under the general supervision of Dr. R.M. Sorensen, Chief, Coastal Processes and Structures Branch, and Mr. R.P. Savage, Chief, Research Division.

Technical Director of CERC was Dr. Robert W. Whalin, P.E., upon publication of the report.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

CONTENTS

		Page
	CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI)	6
I	INTRODUCTION	7
II	FLOATING BREAKWATER SITES	8
	1. Ketchikan, Alaska	8
	2. Sitka, Alaska	15
	3. Tenakee Springs, Alaska	23
	4. Auke Bay, Alaska	29
	5. Friday Harbor, Washington (Port of Friday Harbor)	33
	6. Friday Harbor, Washington (University of Washington Oceanographic Laboratory)	39
	7. Blaine, Washington	42
	8. Langley, Washington	47
	9. Everett, Washington	50
	10. Port Orchard, Washington	53
	11. Camas-Washougal, Washington	56
III	SUMMARY AND CONCLUSIONS	60

TABLE

Winds at Japonski Airport, Sitka, Alaska	20

FIGURES

1	Ketchikan, Alaska	9
2	Photos of floating breakwater, Ketchikan, Alaska	10
3	Typical breakwater module	12
4	Layout for Ketchikan floating breakwater	13
5	Photos of gaps at both north and south of harbor, Ketchikan, Alaska	16
6	Sitka breakwater	17
7	Sitka, Alaska	18
8	Photos of facilities at Thomsen Harbor, Sitka, Alaska	19
9	Photos of module connections, Thomsen Harbor	22
10	Tenakee Springs, Alaska	24
11	Floating breakwater layout, Tenakee Springs, Alaska	26
12	Photos of floating breakwater, Tenakee Springs, Alaska	27
13	Replacement module connector for floating breakwater Tenakee Springs, Alaska	28
14	Photos of deterioration and patching, Tenakee Springs, Alaska	30

CONTENTS

FIGURES--Continued

		Page
15	Auke Bay, Alaska	31
16	Photos of floating breakwater sections, Auke Bay, Alaska	32
17	Friday Harbor, Washington	34
18	Windspeed-duration curves, Friday Harbor, Washington	35
19	Cross section of Port of Friday Harbor breakwater	36
20	Layout of Port of Friday Harbor breakwater	37
21	Photos of the Port of Friday Harbor floating breakwater	38
22	Photos of University of Washington Oceanographic Laboratory, Friday Harbor	41
23	Semiahmoo Spit Marina, Blaine, Washington	43
24	Module connection, Semiahmoo Spit floating breakwater	44
25	Semiahmoo Spit Marina anchor detail	45
26	Photos of the module detail of the Semiahmoo breakwater	46
27	Floating tire breakwater, Langley, Washington	48
28	Windspeed-duration curves, Puget Sound	49
29	Photo of floating tire breakwater, Langley, Washington	50
30	Port of Everett, Washington, floating breakwater site	51
31	Photos of the floating breakwater at the Port of Everett Washington	52
32	Port Orchard floating breakwater site	54
33	Floating breakwater and marina, Port Orchard, Washington	55
34	Schematic drawing of module connection, Port Orchard floating breakwater	55
35	Photos of anchor chains at the Port Orchard floating breakwater	57
36	Camas-Washougal floating breakwater	58
37	Photos of the Port of Camas-Washougal floating breakwater	59
38	Photos of the main section of the Port of Camas-Washougal floating breakwater	61

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

FLOATING BREAKWATER FIELD EXPERIENCE, WEST COAST

by
Eugene P. Richey

I. INTRODUCTION

The increased demand by the boating public and industry for more moorage facilities challenges the planners and designers of small-craft harbors to explore all alternatives in developing harbors that have adequate protection from wind waves and boat wakes. Most of the natural harbors developed near population centers, where boating demands are greatest, are overcrowded. Floating breakwaters have become an alternative with an active potential in future harbor-marina design. The floating breakwater has been adopted at a number of sites where water depth or other constraints render a fixed structure too costly, and is proposed for countless others. Although there are other uses for floating breakwaters, such as in waterfront construction and operation, log rafting in the timber harvesting industry, beach erosion control, etc., the most prominent applications relate to the small-craft harbor or marina.

On location, the floating breakwater is subject to random wave loadings which can induce motions with components in all directions. The intended job of the breakwater is to reduce the incident wave system to an acceptable level. The transmission characteristics of this reduction capability are very sensitive to the period (or length) of the incident wave field. Numerous reports on model tests of transmission characteristics are available, but reports on actual field experiences with floating breakwaters are few. Although several floating breakwaters have been in use for as long as 8 years, there has been little information exchanged as to the type of breakwater, the anchorages, and the connections between units. These are considered major points of interest in improving the design of floating breakwaters.

To cover these points, the following questions were established as a checklist for evaluating field experience with construction and subsequent performance of floating breakwaters:

(1) What were the site conditions and why was the floating breakwater chosen?

(2) How was it deployed?

(3) Were there any unusual installation problems?

(4) What anchoring and connector systems were used?

(5) Have there been any fouling, corrosion, or fatiguing problems?

(6) What maintenance has been carried out?

(7) Have any environmental problems (shoreline changes, icing, stability) been encountered?

(8) Does the structure serve functions other than wave attenuation?

(9) What changes in any step from design to operation would be done differently now?

(10) Has the structure served its intended purpose?

This report provides an evaluation of 11 floating breakwater installations located in the Pacific Northwest--the thrust of the evaluation being the questions listed above. The results of each site evaluation are presented, and a list of conclusions summarizes the overall field performance of floating breakwaters.

II. FLOATING BREAKWATER SITES

1. Ketchikan, Alaska.

a. Location. The Bar Point Harbor breakwater is located on the north side of Tongass Narrows, a fjordlike waterway, at Ketchikan, Alaska (Figs. 1 and 2). There are 390 moorage spaces planned for both pleasure and fishing craft. Most of the boating activity occurs in the period 15 June to 1 November, which spans the seasons for tourism, pleasure craft, and fishing.

b. Site Conditions. The fetch toward the southeast is about 8 miles, about a half-mile across the waterway and practically unlimited toward the northwest. Structures along the shoreline shield the breakwater along the southeast-northwest line. The wind waves travel nearly parallel to the breakwater, and sustained windspeeds of 45 to 50 miles per hour with gusts to 70 miles per hour are to be expected most winters.

Tide data are as follows:

Highest (estimated):	19.5 feet
Mean higher high water (MHHW):	15.4 feet
Mean:	8.0 feet
Mean lower low water (MLLW):	0.0 foot
Lowest (estimated):	-5.0 feet

Tidal currents are from south to north on both flood and ebb, with maximum about 6 knots according to harbormaster; National Oceanic and Atmospheric Administration (NOAA) tidal current data report only 1.2 knots. Bottom elevations are as follows:

Along inner row of anchors	-20 to -60 feet
Along breakwater:	-50 to -70 feet
Along outer row of anchors:	-100 to -110 feet

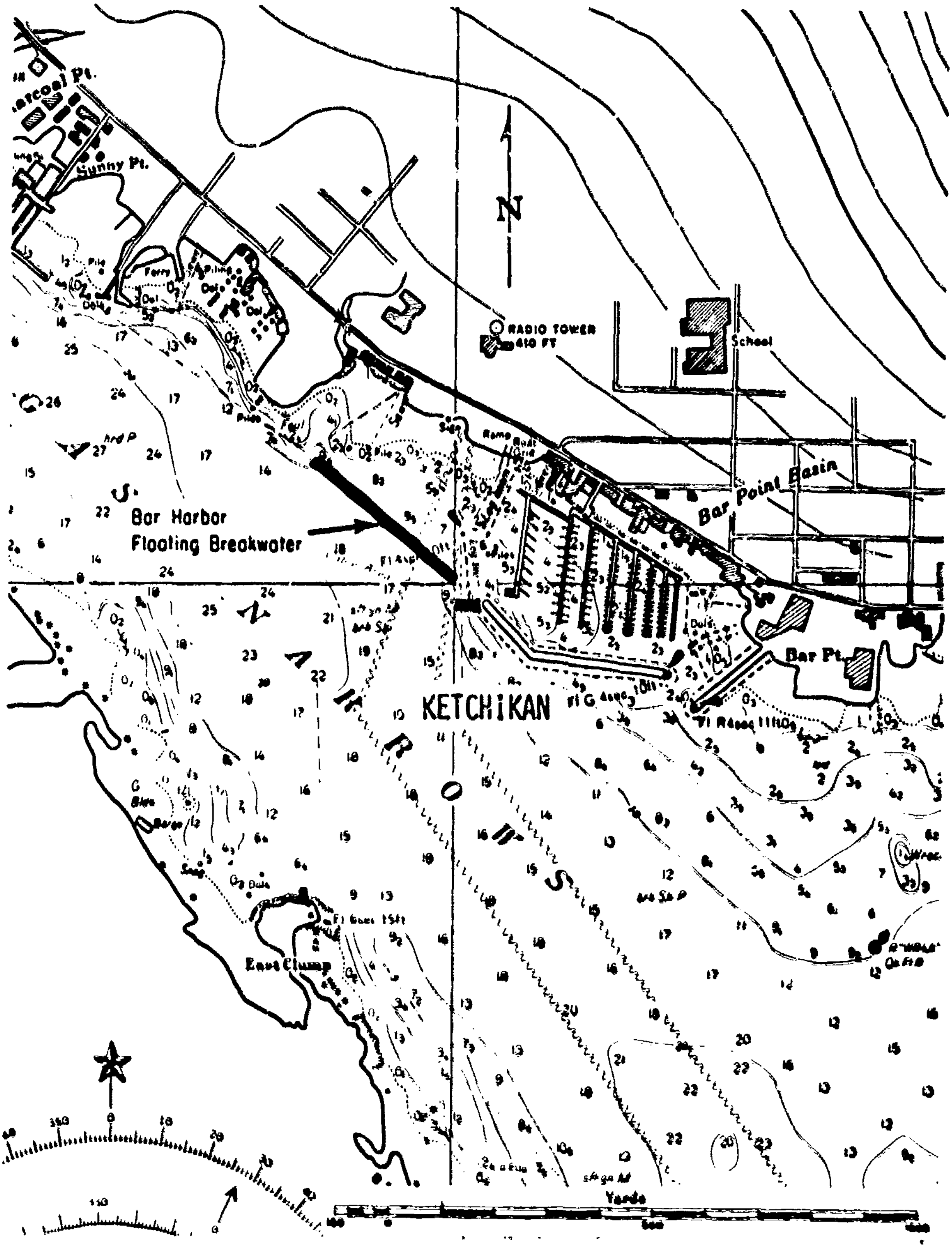


Figure 1. Ketchikan, Alaska (from NOS chart 17430).

a. Main entrance to Bar Harbor.

b. Main floating breakwater, south to north view.

Figure 2. Photos of floating breakwater, Ketchikan, Alaska.

No recordings of wave conditions have been made. Boat wake loadings are frequent, because boat traffic is heavy, with vessels ranging in size from small pleasure craft to the fishing fleet size, including heavy trawlers, purse seiners, oceangoing cruise ships, ferries, and freighters.

c. Breakwater Description.

(1) Design. The structure is of the Alaska-catamaran or ladder type, 23 feet wide and 6 feet deep, made of posttensioned, foam-filled modules of lightweight reinforced concrete (Fig. 3). The main breakwater is 963 feet long, parallel to the shore (and Tongass Narrows). A separate 120-foot section was positioned off the end of a rock breakwater forming Bar Harbor No. 2 to attenuate waves from the south. The layout is shown in Figure 4. A 165-foot section planned at the northern end was omitted to avoid conflict with a loading pier. Anchor chains at 60-foot intervals connect the breakwater to concrete anchor blocks weighing 18 tons on the inside and 60 tons on the outside; 100-ton anchors hold the 120-foot section.

(2) Installation. Installation began in October 1979. Storm damage occurred during construction to unassembled units moored at the site. The cost (1980) of the breakwater was $1,400 per foot. Those responsible for the breakwater design, construction, and operation are as follows:

Owner-Operator:	City and Borough of Ketchikan, Alaska
Designers:	U.S. Army Engineer District, Alaska Anchorage, Alaska
	Tryck, Nyman and Hayes Anchorage, Alaska
Builder:	Concrete Technology Tacoma, Washington
Installers:	Dawson Construction Bellingham, Washington
	Smart Crane Company Ketchikan, Alaska

The following comments on installation were abstracted from an interview with one of the installers of Smart Crane Company (B. Smart):

> The major difficulty experienced was stringing, flushing, greasing, and sealing the posttension cables in the stress-strand ducts. Holes between adjacent modules rarely lined up. The general assembly technique was a difficult procedure to carry out in field conditions. Larger diameter, lower stressed galvanized rods would have been easier to use. The 1-inch cable with threaded studs used to join 240-foot sections was difficult to tighten, since the cable rotated as the nuts were turned. Towing of the 240-foot sections was very difficult except at a very low speed. A skiff was almost as effective as a tug. The accurate placement of the outer row of anchors on a stable site was difficult because of the anchor weights.

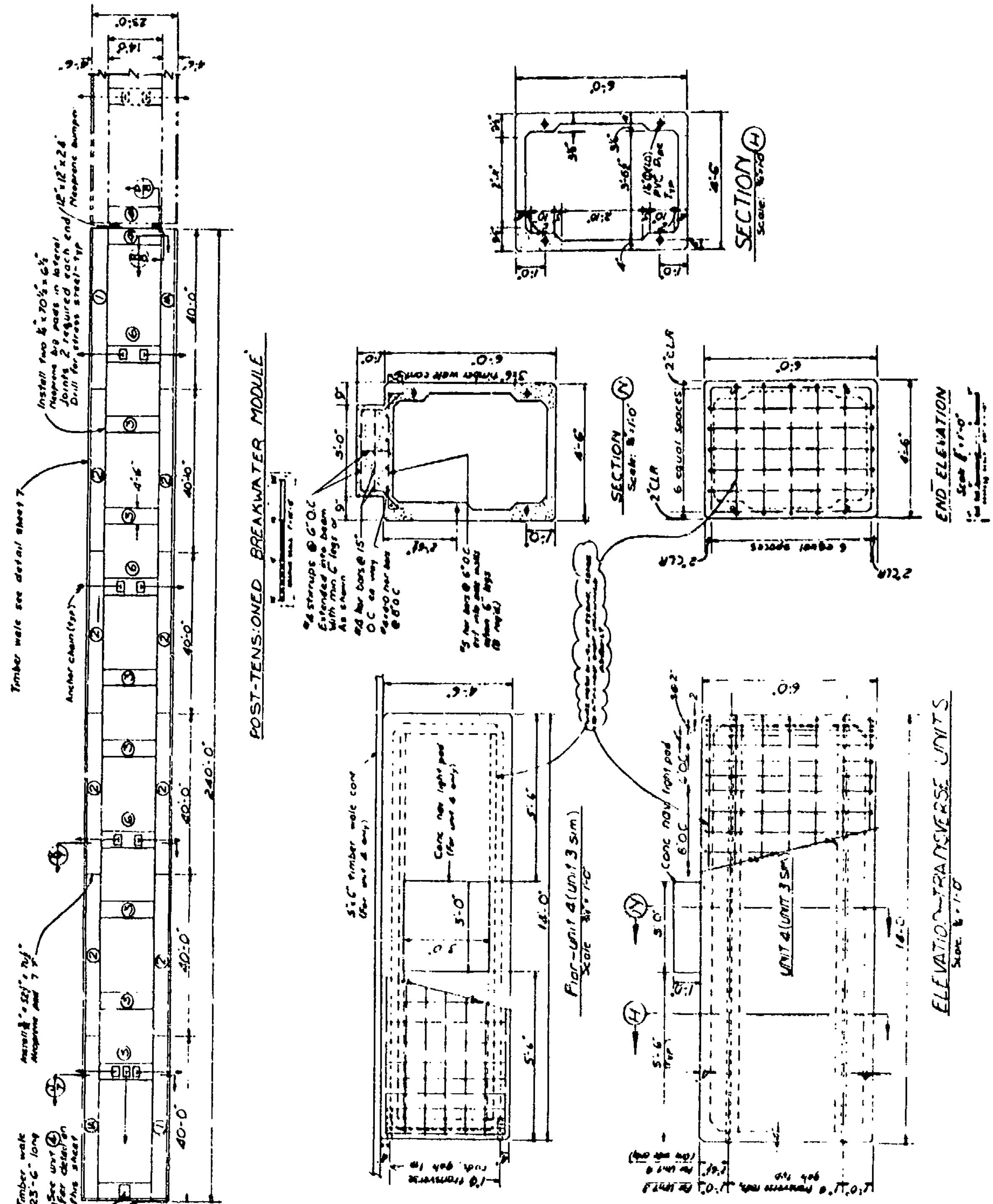


Figure 3. Typical breakwater module.

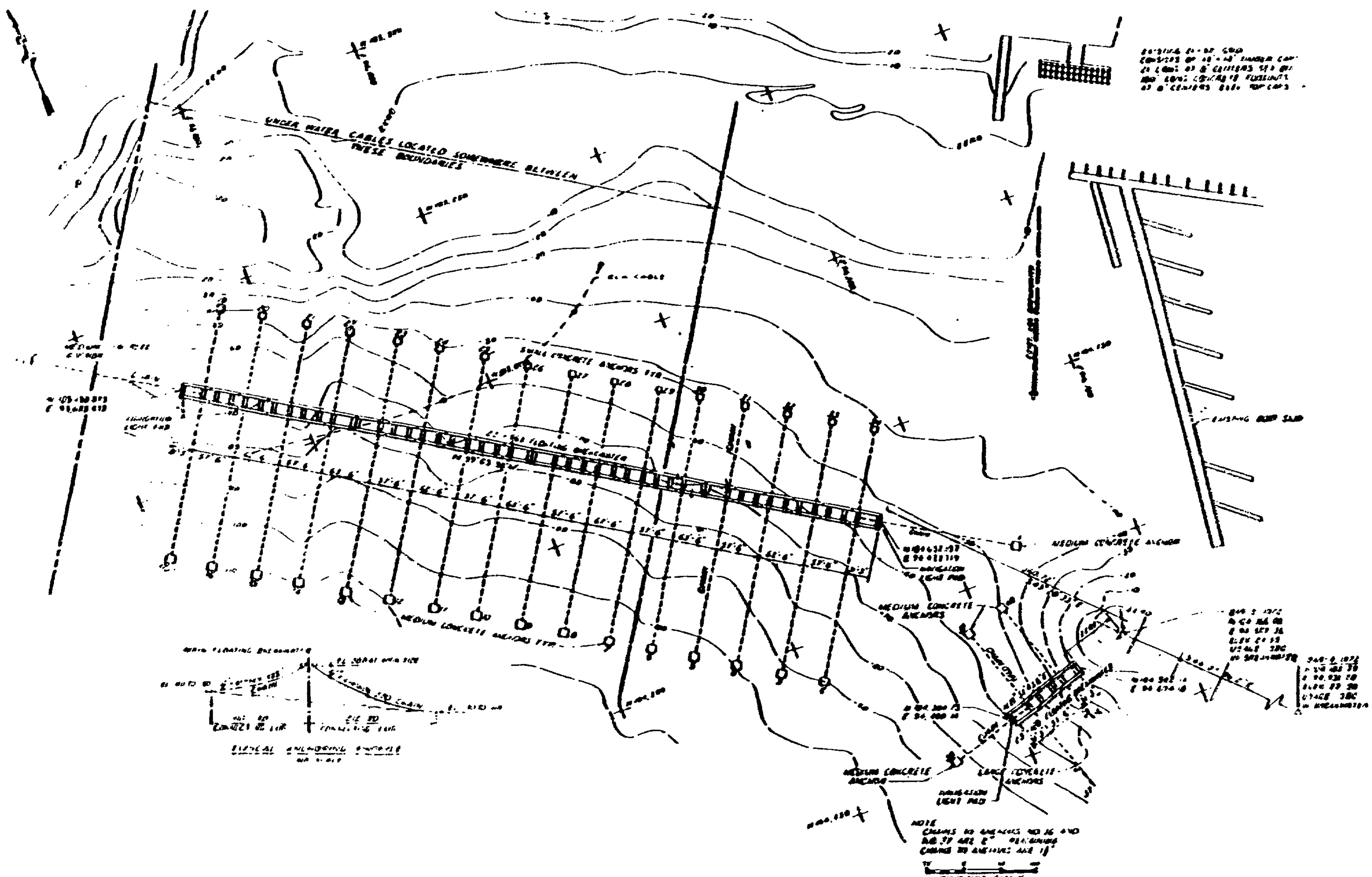


Figure 4. Layout for Ketchikan floating breakwater.

bottom slope and bottom conditions; 6- to 8-ton steel anchors would have been much better. Special receptacles for navigation lights should be designed into the breakwater units.

The following comments on the design and installation of the floating breakwater were provided by the U.S. Army Engineer District, Alaska:

> Use epoxy coatings over steel reinforcement to reduce corrosion. Provide positive locking devices at the ends of connecting cables. Obtain sufficient bottom data to allow workable anchorage designs. Some problems with anchor placement were experienced owing to a lack of good topography and knowledge of what materials the anchors would be set on. Consideration should be given to providing a method of regreasing tendons and cables. This design was made with the premise that vessels would not be allowed to tie up to the breakwater. The design must provide heavy wales and recessed bolts to allow for protection of the breakwater from vessels that tie up temporarily. Provide for connections on end units for possible future changes in configuration. These can be temporarily sealed with knockouts. Adequate lighting should be provided for foul weather visibility of the breakwater to supplement U.S. Coast Guard furnished lights. Radar visibility should also be provided. Better quality control should be achieved to eliminate careless slopping of grease on concrete surfaces adjacent to the prestressed cable anchors. Preparation of construction specifications should consider the requirement for a specific assembly method, such as on a sinkable barge, or in the water, or in a dredged area which can be flooded. Materials and procedures used should be compatible with the assembly method. Construction problems were experienced during the process of capping the prestress cable heads in the water. Further consideration might be given to a cofferdam design which would allow this to be accomplished in the dry. Consideration should be given to monitoring anchor chains to determine actual mooring forces to compare with design forces.

(3) Performance. The boat slips had not been installed as of September 1980, so there are no data on breakwater effectiveness. The harbormaster expressed the opinion that the breakwater does perform as expected. Prevailing wind waves attacking the breakwater are at a high incident angle, and the alinement seems good, with lower transmission than for normally incident waves.

The installer (B. Smart) was on a barge tied to the breakwater during a storm with gusts up to 70 knots. He reported wave periods of 3.5 to 4 seconds and wave heights to 4 feet, based on the height of the barge rail above mean water level: ". . . the breakwater really knocked the waves down." Three wavelengths were observed in the 100-foot barge length, which would correspond to about a 2.7-second period, rather than the 3 to 4 seconds reported.

Logs up to 2 feet in diameter have worked their way into the interior spaces of the breakwater, but have conveniently worked their way out. There has been rapid marine growth on the submerged surfaces.

Although Coast Guard regulations require lights only at the ends of the breakwater, intermediate lights and radar targets would be helpful to navigators because the breakwater profile is low, long, and difficult to see in the dark, stormy weather that is so frequent at the site. The breakwater has only a 12-inch freeboard, instead of the 18 inches called for in the design. A fabrication error is believed to have caused the overdraft.

Wakes from vessels moving down Tongass Narrows from north to south move directly through the opening between the end of the rock breakwater forming Bar Harbor No. 2 and the southern end of the floating breakwater, causing motion of the slips and boats in Bar Harbor. The breakwater reduces the regular boat wake quite well, but the potential exists for the large fishing vessel, tug, or freighter to set a wake that will be very evident behind the breakwater.

d. Discussion. The water depths at the site indicate the floating breakwater is the logical type to meet the local need for additional moorage space. In the design of future breakwaters of this type, attention should be given to the difficulties encountered in the field in carrying out the post-tensioning operation, the connection of modules, and the placement of the heavy anchors. The omission of the breakwater section at the north end of the harbor (Fig. 5) means that some of the mooring area will receive undamped wave energy. Possibly, the placement of slips in this section should be delayed until alternative protection is provided.

South-traveling wind waves and boat wake readily pass into Bar Harbor No. 2 between the south end of the floating breakwater and the north end of the rock breakwater. Some corrective alternatives are as follows:

(a) Add a stub section about normal to the south end of the present floating breakwater. Alinement would have to give due regard to waves from the south being reflected in adverse directions.

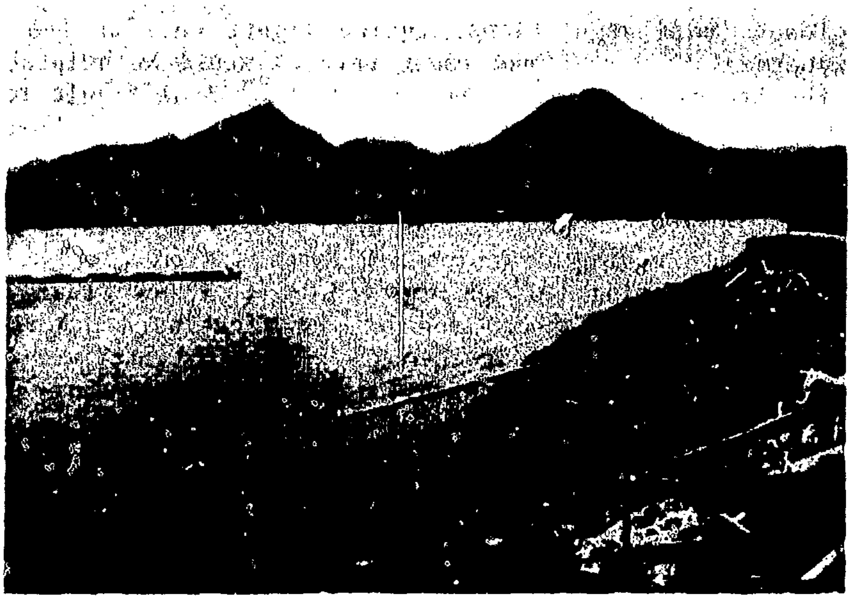
(b) Reinstall the log breakwater (or similar) that previously shielded Bar Harbor No. 2.

(c) Adjust the anchor system of the main breakwater to allow it to be rotated about 5°, and add an extension to narrow the harbor entrance from its present 400-foot width.

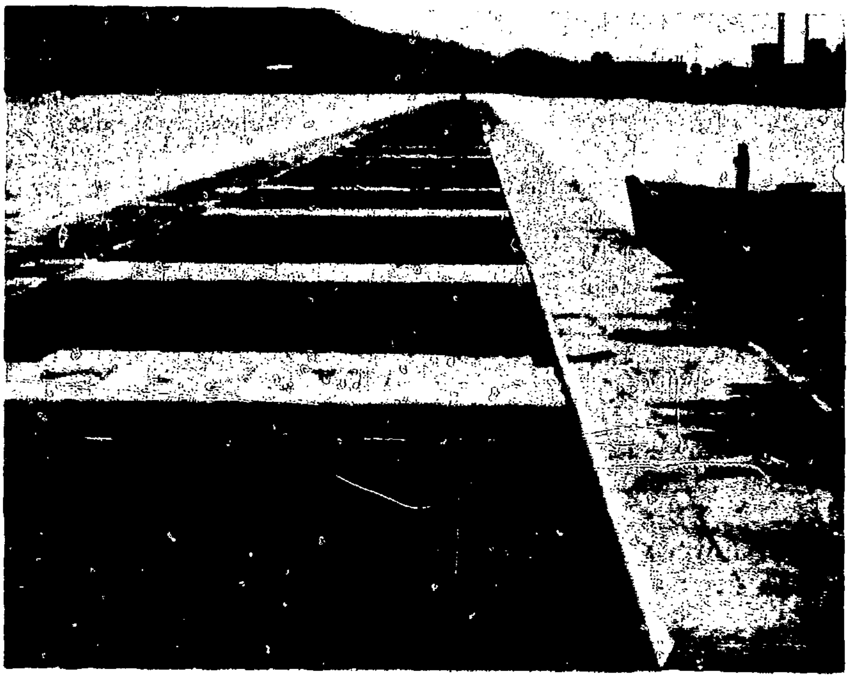
A pragmatic view is to adapt the floating breakwater to accommodate transient moorings. As it is now, transient boaters remove covers from the anchor chain wells, fasten lines to hawse pipe or chains, then leave without replacing the covers. Tiedown cleats, thicker walers, camels, or other fendering systems would be required, along with a walkway to make a connection with the main floats. This connection could be removed during the off-season.

2. Sitka, Alaska.

a. Location. Thomsen Harbor is on the east side of the waterway between Japonski Island and Baranof Island, where Sitka is located (Figs. 6 and 7). The waterway is about 1,300 feet wide and 40 feet deep. The breakwater is used for transient moorage and has a fish-cleaning facility (see Fig. 8) for the convenience of the harbor users.



a. North end of harbor.



b. South end of harbor.

Figure 5. Photos of gaps at both north and south of harbor, Ketchikan, Alaska.

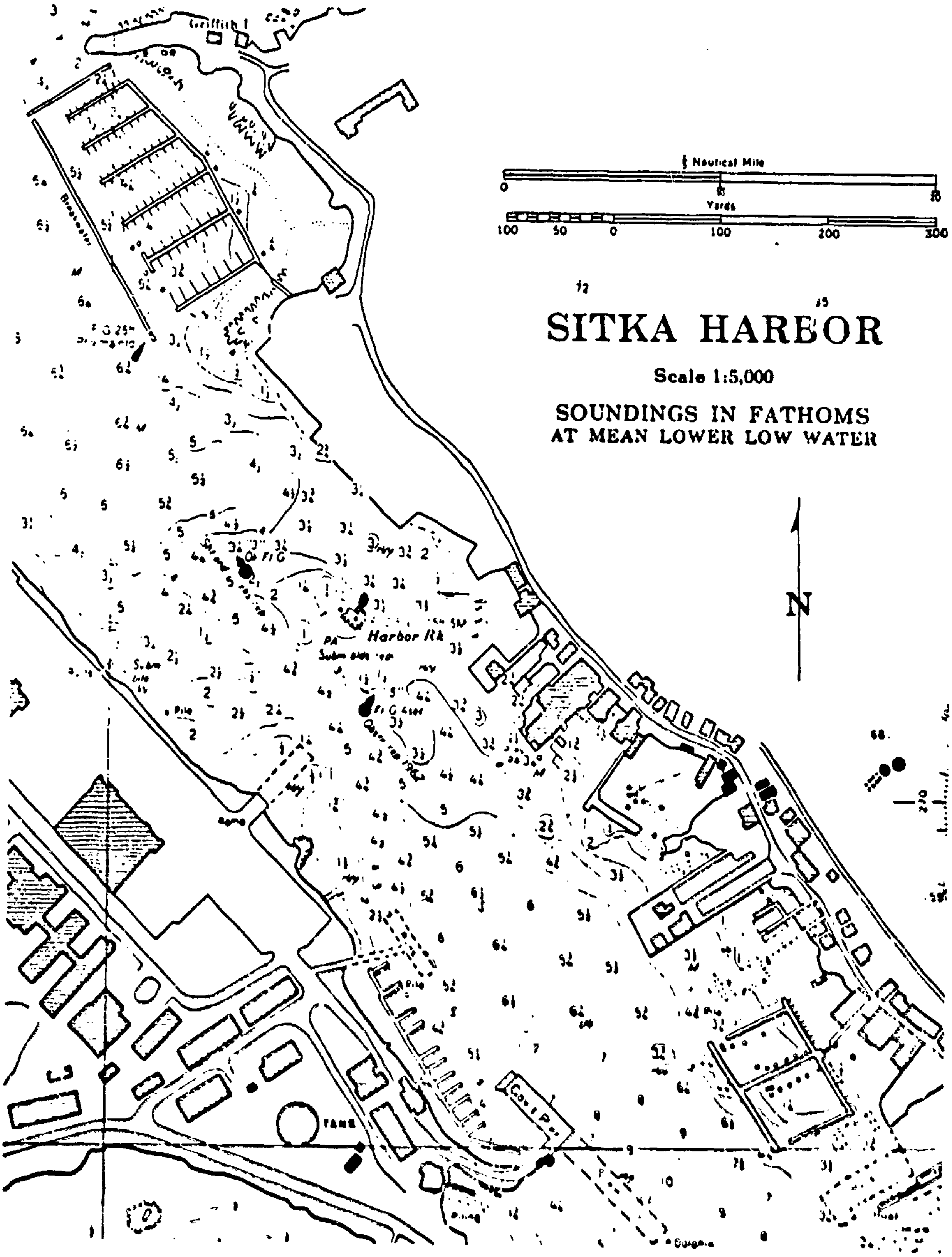


Figure 6. Sitka breakwater (from NOS chart 17327).

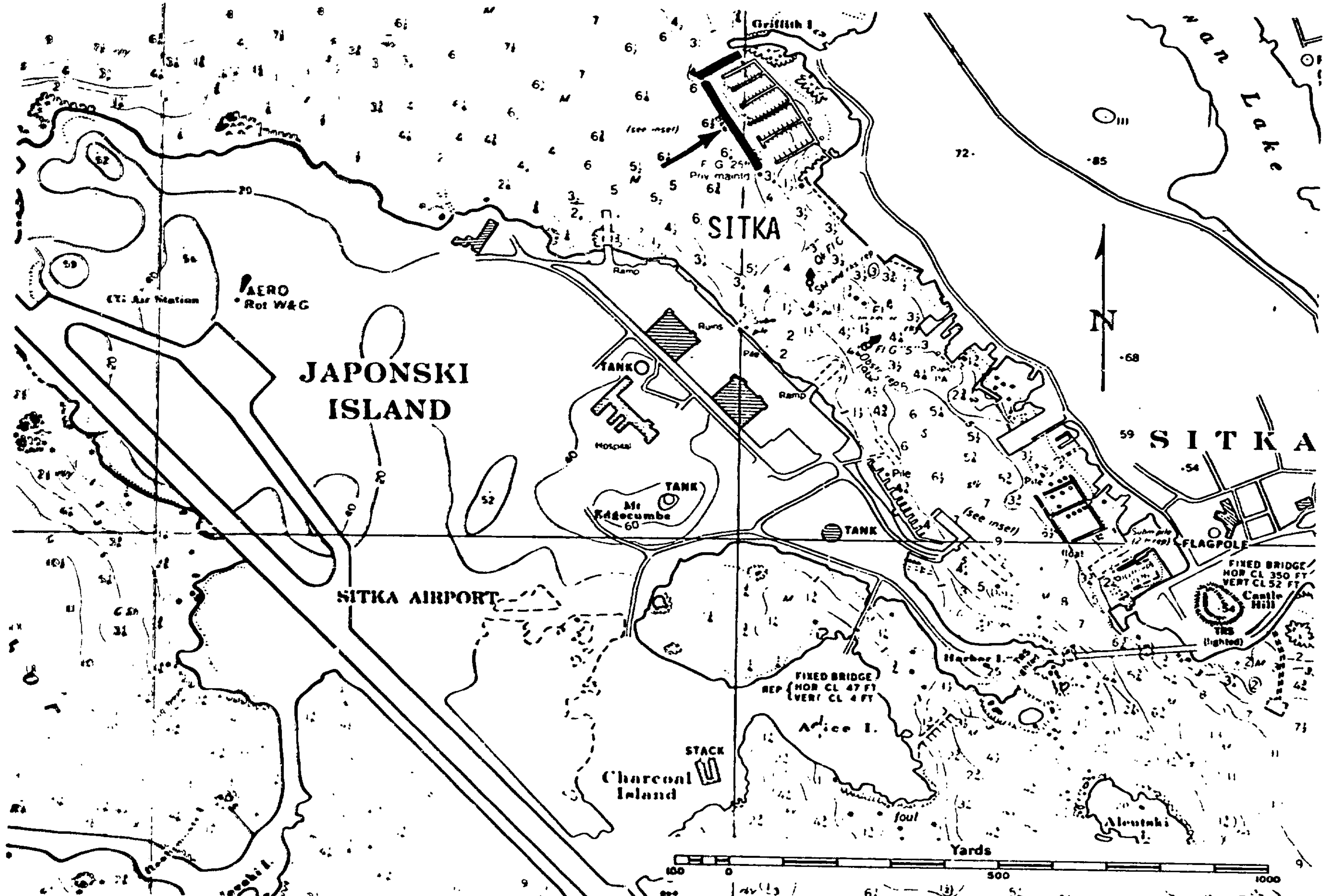
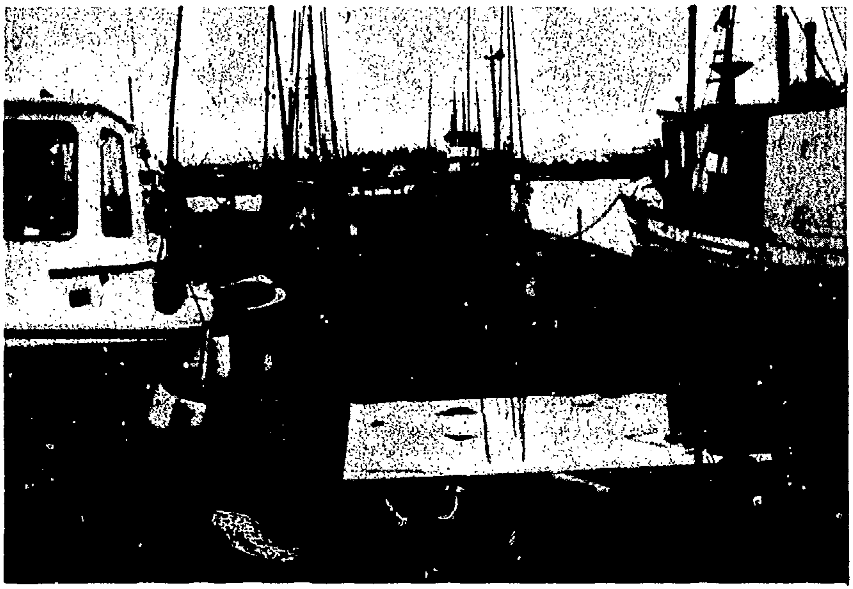
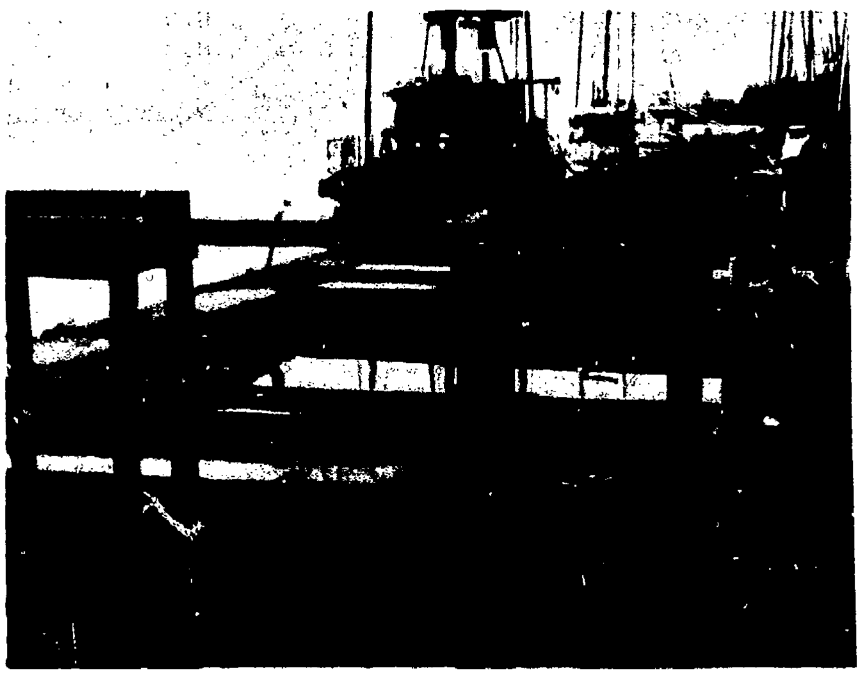


Figure 7. Sitka, Alaska (from NOS Chart 17327).



a. Floating breakwater.



b. Fish-cleaning facility.

Figure 8. Photos of facilities at Thomsen Harbor, Sitka, Alaska.

b. Site Conditions. The principal wave window lies in a 45° sector centered about the northwesterly direction, and has a fetch cluttered by small islands out to about 3.5 nautical miles, then opens into Sitka Sound. The site is effectively shielded from other directions. The winter low-pressure systems off the Alaskan coast generate high winds. Local lore reports that speeds of 60 knots are common. However, the annual summary of winds at Japonski Airport (see Table) indicates that 40-knot winds are rare (Amerman, 1980)[1]. The many islands in the path of the winds must create highly nonuniform wind fields.

Table. Winds at Japonski Airport, Sitka, Alaska (Amerman, 1980)[2]

	Windspeed (kn)							
Direction	0-3	4-10	11-21	22-27	28-40	40+	Pct.	Avg.
N.	1.6	0.5	0.1	0.0	0.0	0.0	2.1	3.0
NNE.	0.2	0.1	0.0	0.0	0.0	0.0	0.2	4.1
NE.	1.7	1.7	0.4	0.0	0.0	0.0	3.8	5.3
ENE.	0.3	0.6	0.3	0.0	0.0	0.0	1.3	6.6
E.	3.4	6.3	1.6	0.1	0.0	0.0	11.3	6.5
ESE.	1.0	4.7	4.0	0.3	0.1	0.0	10.1	10.7
SE.	3.7	10.0	4.1	0.2	0.1	0.0	18.1	7.9
SSE.	0.3	0.9	0.3	0.1		0.0	10.1	8.1
S.	3.3	4.7	1.4	0.1		0.0	9.5	6.4
SSW.	0.5	1.6	0.3		0.0	0.0	2.5	6.6
SW	2.2	4.6	0.6			0.0	7.3	5.6
WSW.	0.2	0.7	0.1	0.0	0.0	0.0	1.0	5.4
W.	2.1	2.1	0.1	0.0	0.0	0.0	4.3	4.2
WNW.	0.6	1.6	0.4	0.0	0.0	0.0	2.6	6.8
NW.	3.1	5.5	1.2			0.0	9.9	6.0
NNW.	0.3	0.4	0.1	0.0	0.0	0.0	0.8	6.0
Calm	13.4							
Total	24.5	46.2	14.8	0.8	0.2	0.0	86.6	6.0

The harbor serves a fishing fleet and pleasure craft with moorage fees at $6 per foot per year, with a 2-year waiting list. The mix of boats is shifting toward larger sizes.

Tide data are as follows:

High: 12.0 feet MLLW

Diurnal range: 9.4 feet

Mean range: 7.7 feet

Low: 5.0 feet MLLW

[1]AMERMAN, R., "Sitka Small Boat Harbor Site Study," State of Alaska, Department of Transportation and Public Facilities, Division of Harbor Design and Construction, Apr. 1980.

[2]AMERMAN, R., op. cit.

Tidal currents are 1 knot maximum on both flood and ebb. Bottom elevations are -35 feet MLLW under the long leg of the breakwater and -6 feet MLLW at the shoreward end of the short leg.

Waves estimated at 4 feet in height have been reported coming in from the northwest. These strike the breakwater at an appreciable angle and are attenuated quite effectively. Ocean swell penetrates the offshore islands and passes through the breakwater. Boat wake is a common loading from the pleasure craft, fishing vessels, and the occasional tug which ply the channel.

c. Breakwater Description.

(1) Design. The structure was the second one built of the Alaska-catamaran or ladder type, and consists of 3- by 5- by 18-foot reinforced, lightweight concrete pontoons cast over solid polystyrene foam blocks. Three pontoons were posttensioned on site to form 60-foot modules, which were then linked with a chain-rubber back fender connector as illustrated in Figure 9. The main leg of the breakwater is 685 feet long; the shorter one is 275 feet long, with a 3.5-foot draft.

Anchoring was accomplished with 1-1/4- and 1-3/8-inch galvanized stud-link chain at each module fastened to stake piles. Where the stake piles could not be driven to adequate penetration, as determined by jetting tests before installation, concrete blocks were added to increase lateral resistance; 29-ton units were used on the windward leg of the north-facing (short) leg of the breakwater, and 12-ton units were used on the west-facing (long) leg. A space of about 6 feet is maintained between the two breakwaters at the junction of the "L" base. This design feature was used to avoid stress problems likely with a positive connection.

(2) Installation. The breakwater was installed in 1973 at a cost of $480 per foot. Those responsible for the breakwater design, construction, and operation are as follows:

Owner-Operator:	Owned by State of Alaska, but operated by City of Sitka
Designer:	State of Alaska, Juneau Division of Harbor Design and Construction
Design Engineer:	D.S. Miller
Fabricator:	Bellingham Marine Industries Bellingham, Washington
Installation:	Units were fabricated in Bellingham and barged to the site. Basic dimensions of the breakwater were chosen to facilitate shipping and onsite erection with equipment readily available in the area. T.O. Paddock Company, Juneau, was the erection contractor.

a. Module connection.

b. Module connection with fender missing.

Figure 9. Photos of module connections, Thomsen Harbor.

(3) Performance. The users are satisfied with protection afforded by the breakwater. Mooring lines and dispositions are adapted to accept the swell and boat wake that enter the harbor.

No underwater components of the breakwater have been checked. The only maintenance problem has been repairing and replacing worn chain links connecting the modules; several rubber bumpers, part of the connecting systems between modules, have disappeared (Fig. 9). There is some correlation between missing bumpers and worn chain links. Although the breakwater is not considered the responsibility of the harbormaster, he has been welding worn connecting links and checking for other stress points.

Lightweight concrete was used in forming the breakwater modules. There are several spall areas that have been attributed to banging of corners, etc., during transport and construction. Some of these were successfully patched with epoxy shortly after construction. Some of the reinforcement is exposed and rusty, but spalling is slow, if at all.

Because of the shortage of mooring spaces, large trawlers tie up to both sides of the breakwater, and may be the cause of the nonlinear breakwater alinement observed. The mass per foot of the trawlers may exceed that of the breakwater. A differential draft has developed on some sections, with 14 inches of freeboard on one side of a pontoon and only 12 inches on the other side. No explanation is offered. Marine growth at Sitka is not as active as at Ketchikan.

d. Discussion. The breakwater has performed satisfactorily during its 7-year life. Although the swell transmitted into the harbor has been a nuisance, the users have adapted. Maintenance problems have been minor, mostly involving replacing worn chain links. Underwater components should be inspected. The present 3-link chain-rubber bumper module connections should be replaced with a newer, improved design such as that employed in the revisions at the Tenakee Springs breakwater, discussed in the following section. Transient boats usually tie up at a floating breakwater, whether or not such use is authorized. Designs should recognize this pattern or operations personnel should be given time and authority to restrict tie-ups.

3. Tenakee Springs, Alaska.

a. Location. Tenakee Springs, Alaska (Fig. 10), is a small village about 60 miles southwest of Juneau, Alaska, with about 80 permanent residents who are income-dependent upon fishing, crabbing (cannery recently closed), logging, retirement incomes, and limited tourism.

b. Site Conditions. A small natural harbor is unprotected from the west with a fetch of about 5 miles out of Crab Bay around to the southeast where the fetch is about 3 miles from Corner Bay. Storms from these directions are common winter occurrences. There are no wind records for the site, but according to local residents, speeds ranging from 60 to 70 miles per hour have occurred.

Tide data include a maximum range from -5 to +20 feet MLLW. Tidal currents are less than 1 knot at the breakwater site. Bottom elevations are as follows:

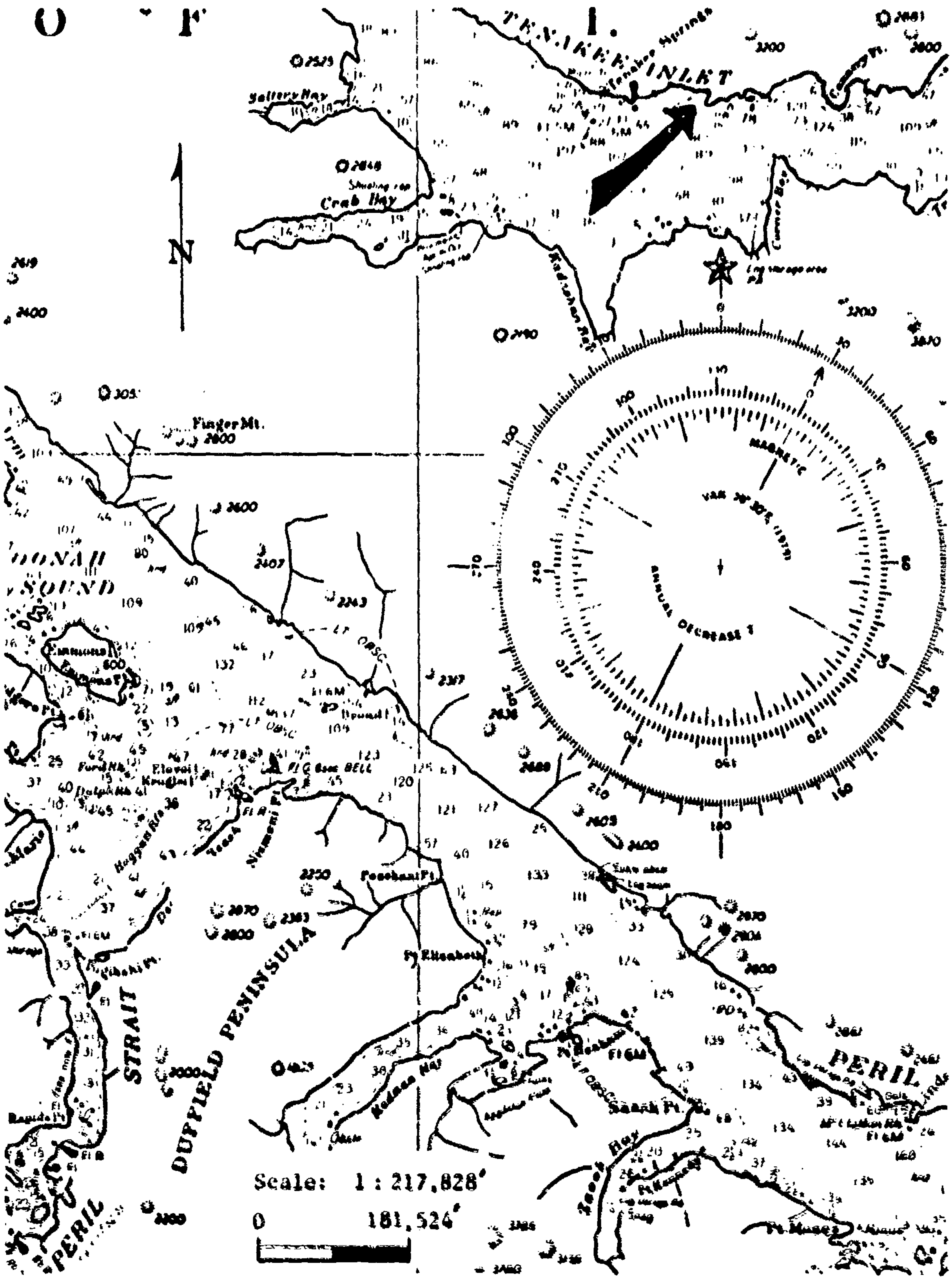


Figure 10. Tenakee Springs, Alaska (from NOS chart 17320).

Along inner row of anchors:	-15 feet MLLW
Along breakwater:	-30 feet
Along outer row of anchors:	-45 to -55 feet

A wave monitoring program was in operation during the winter season of 1973-74. However, maximum windspeeds recorded were only about 30 knots, which is not representative of the usual winter season when, according to local residents, waves 4 feet and higher occur. Boat wake is not a problem.

The harbor is without power or other amenities. There is no harbormaster nor designated official on the site. The operation is best described as "Alaskan informal." Long-time local residents are a good source of information on the harbor.

c. Breakwater Description.

(1) Design. This structure was the first of the Alaska-catamaran or ladder type, consisting of 3- by 5- by 15-foot reinforced, lightweight concrete pontoons with solid polystyrene foam core. Units of 15 feet were post-tensioned with 1-1/2-inch galvanized bars to form the ladder module, 5 feet deep, 21 feet wide, and 60 feet long, with a draft of about 3.5 feet. Five modules were coupled with chain links and compression bumpers to form a shallow V-shaped breakwater 308 feet long, as shown in Figure 11. The V-joint was a weak link in the system, and was removed in 1977. The alinement was then straightened (see Fig. 12,a) with module connectors of a modified design shown in Figure 13, and an additional 60-foot section of breakwater added to help close off a wave window from the southeast.

Anchor chains of 1-3/8-inch stud links at each of the five 60-foot modules are attached on the harborside to 26-ton concrete anchors and to two 26-ton anchors on the seaward side. A shallow soil layer over rock ruled out the use of stake piles at the site.

(2) Installation. The breakwater was installed in the fall of 1972 at a cost of $425 per foot. It had been designed for field assembly where facilities and equipment size were limited. The pontoons and other components were barged to the site.

Assembly problems were caused primarily by nonsquare faces on surfaces that were to be matched. Some spalling of concrete occurred during the development of the specified post-tensioned forces and was attributed to improper location of reinforcing steel during fabrication. Dimensions for the connecting modules must be accurate to avoid assembly delays. Those responsible for the breakwater design, construction, and operation are as follows:

Designer-Owner-Operator:	State of Alaska Division of Ports and Harbors Division of Harbor Design and Construction Juneau
Design Engineer:	D.S. Miller

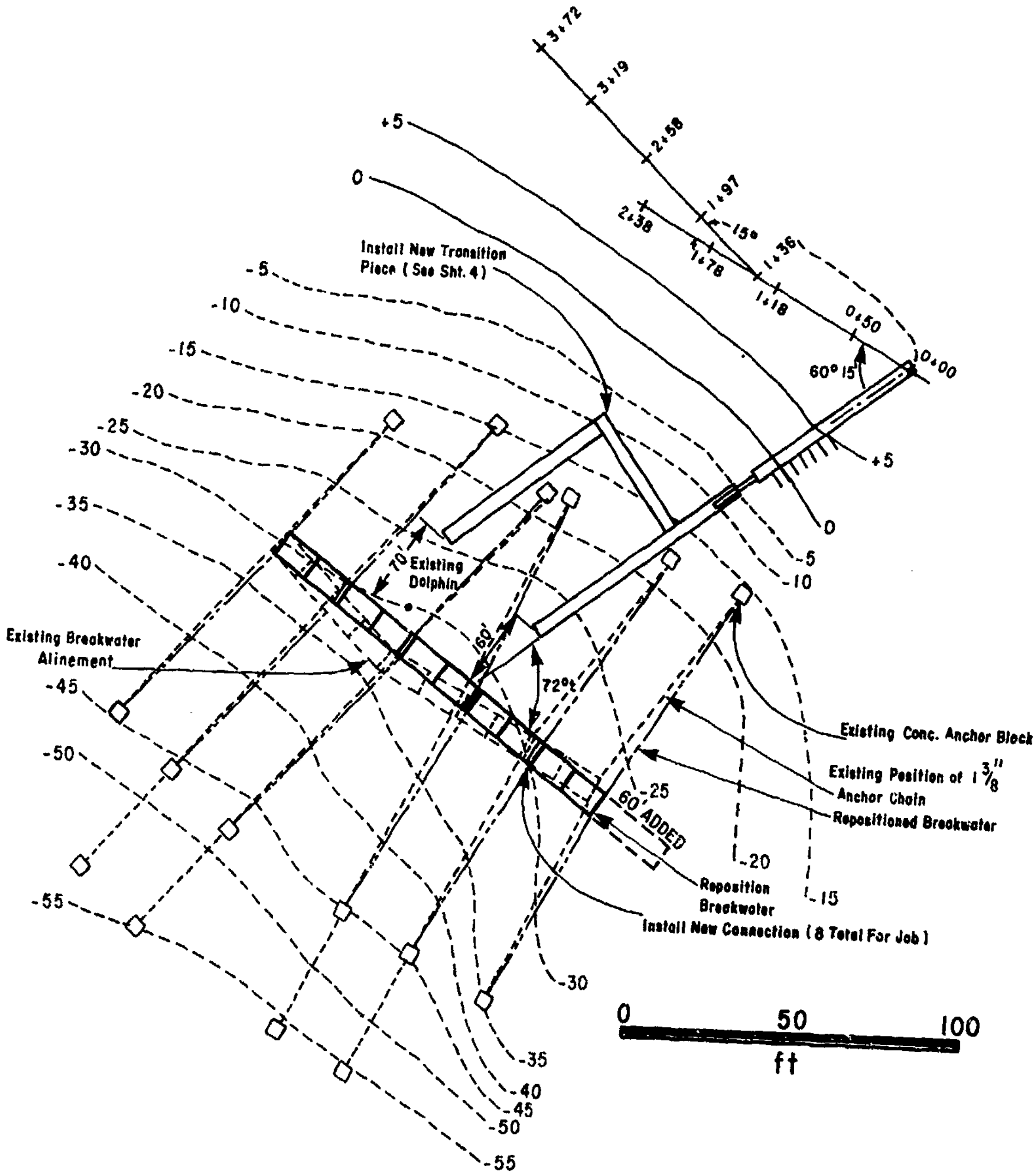


Figure 11. Floating breakwater layout, Tenakee Springs, Alaska.

a. Floating breakwater alinement.

b. Module connection.

Figure 12. Photos of floating breakwater, Tenakee Springs, Alaska.

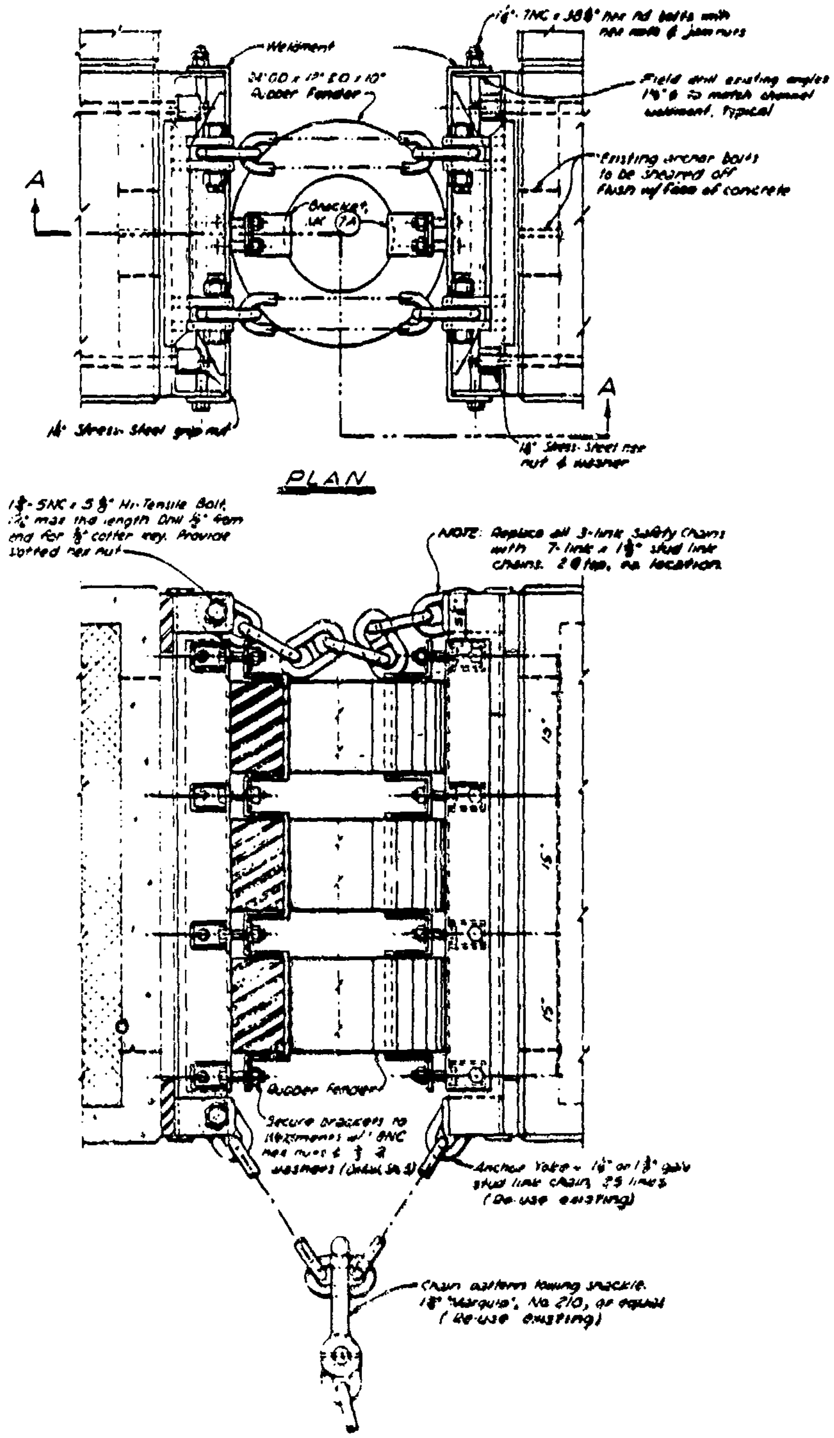


Figure 13. Replacement module connector for floating breakwater, Tenakee Springs, Alaska.

Builder:	Bellingham Marine Industries Bellingham, Washington
Installer:	Martinsen Builders Petersburg, Alaska

(3) Performance. The users are satisfied with the protection afforded by the breakwater. Prior to its installation, winter moorage was risky and the boats often had to be moved to more sheltered waters during storms. The outer chain on the base of the V-section in the initial breakwater layout broke during a storm (D. Miller, personal communication). This connection has been eliminated by the new alinement and new connectors have been installed (see Fig. 12,b).

Some wire and rod reinforcement is exposed and rusted where the concrete has spalled off, as illustrated in Figure 14, but no progressive deterioration is apparent. The spalling seems to have been the result of construction handling and installation, rather than from use-oriented causes.

d. Discussion. The breakwater design is well matched to the site conditions for construction as well as to exposure and use. In 8 years, the only maintenance has been the straightening of the dog-leg alinement, a well-recognized weakness in the initial design layout. The new module connectors also promise to eliminate another weakness--the slack condition that develops as the rubber fender unit loses its resiliency.

4. Auke Bay, Alaska.

a. Location. Auke Bay (Fig. 15), located about 20 miles north of Juneau, Alaska, is a popular moorage for pleasure fishing craft of area residents and transient boats during the summer season.

b. Site Conditions. The upper end of the bay, the breakwater site, is well-sheltered except toward the southeast, where Coghlan Island limits the fetch to about 2.5 miles, except for a very narrow window of about 6 miles. There are no data available on either tides or currents. Currents at the breakwater are not likely to be a concern. No recordings of wake conditions are available.

c. Breakwater Description.

(1) Design and Installation. One 60-foot and two 120-foot lengths of 48-inch-diameter oil pipe surplussed from the Alayeska project were designed as a replacement for a decayed log breakwater shielding a small, privately owned marina at the head of Auke Bay. The breakwater sections were fabricated in Seattle and barged to Juneau where they were off-loaded, as shown in Figure 16, for towing to Auke Bay. A wooden walkway on the pipes provides access to 24-inch pipes, also with walkways, which serve as boat slips. The pipes were ballasted with seawater to a 1-foot freeboard.

The breakwater was installed in July 1980 at a cost of $400 per foot. Anchor chain connection holds the breakwater in place. Those responsible for the breakwater design, construction, and operation are as follows:

a. Exposed reinforcement.

b. Epoxy patch.

Figure 14. Photos of deterioration and patching, Tenakee Springs, Alaska.

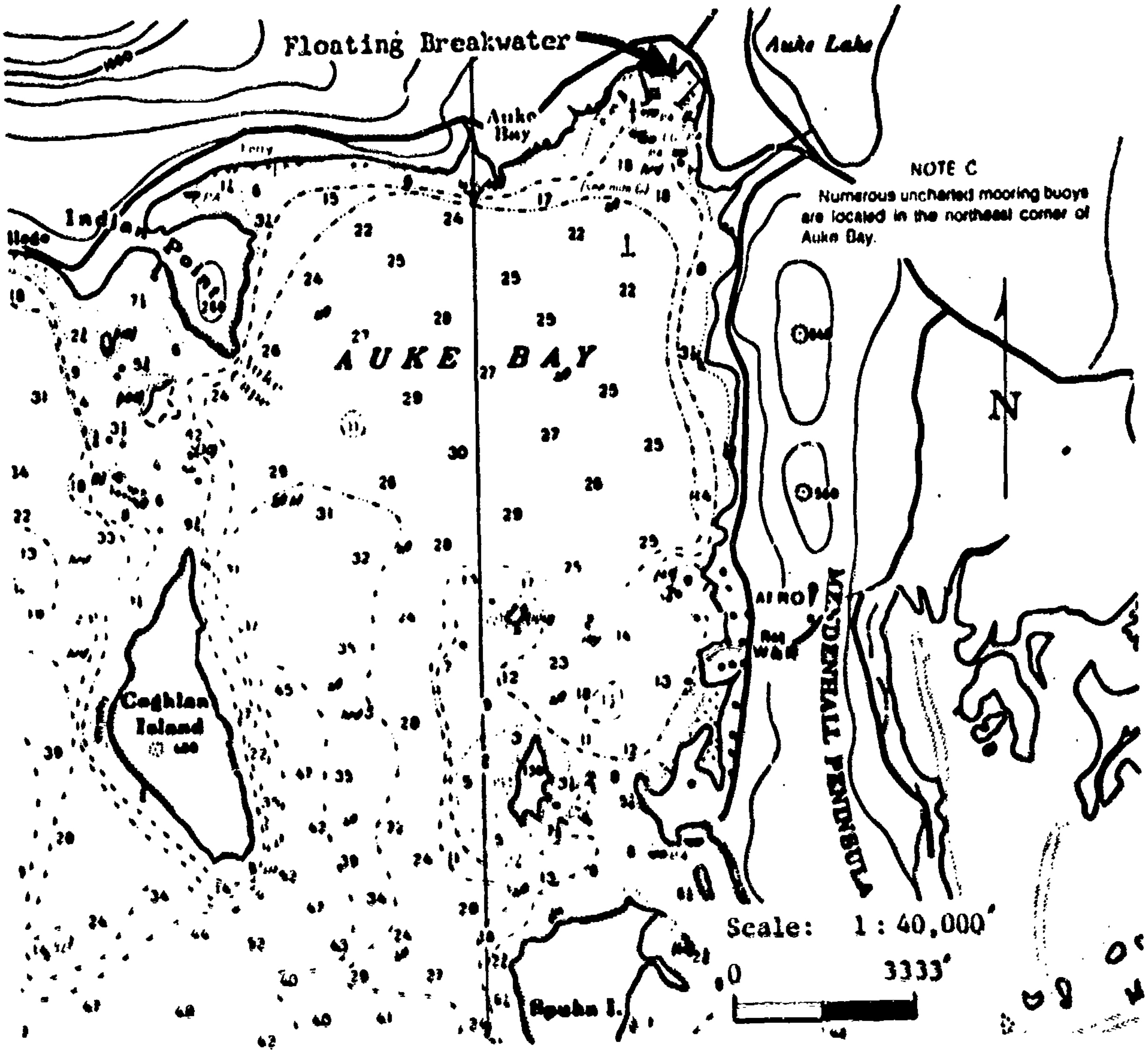


Figure 15. Auke Bay, Alaska (from NOS chart 17315).

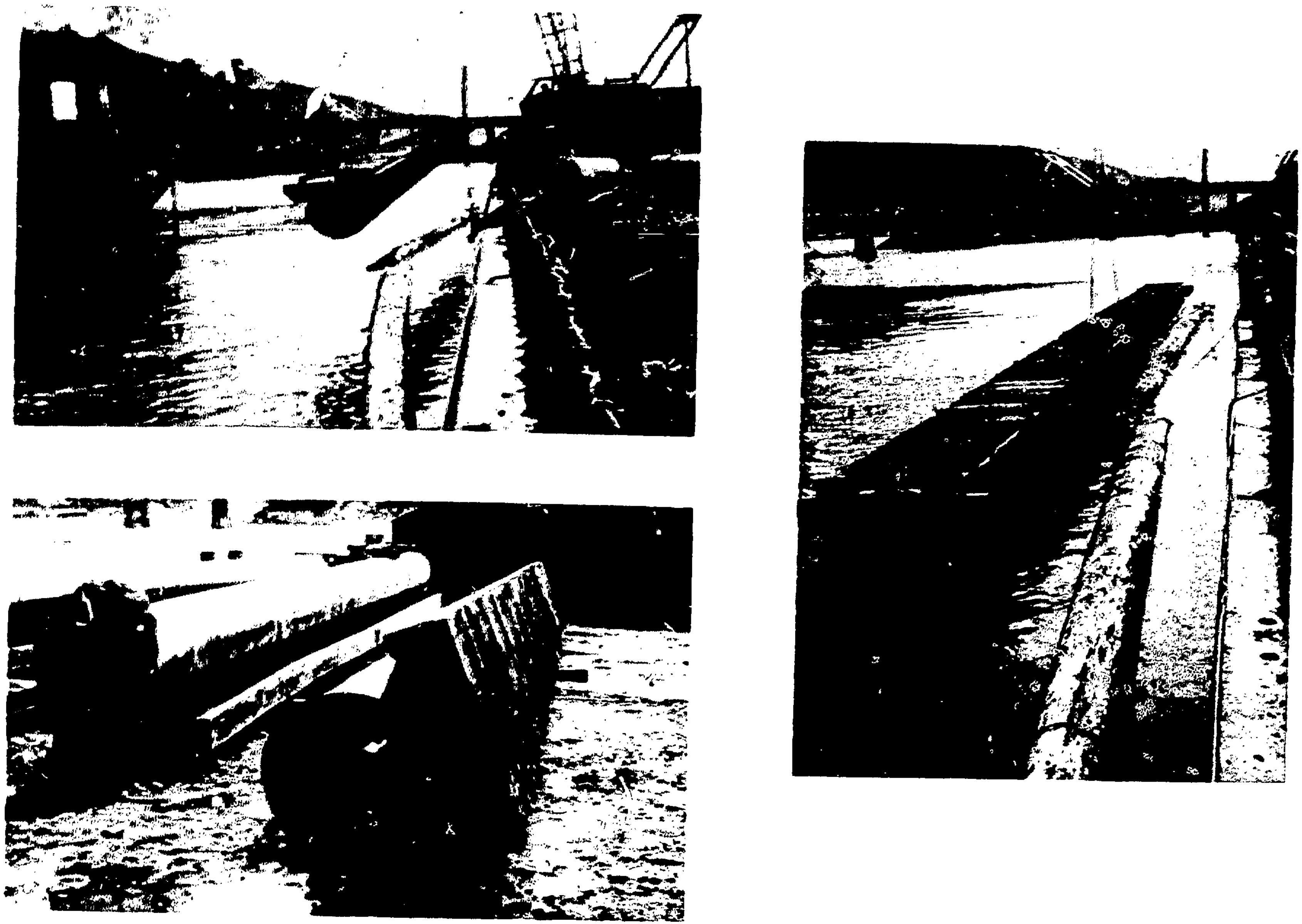


Figure 16. Photos of floating breakwater sections, Auke Bay, Alaska.

Owner: Robert Weems

Designer: David S. Miller

(2) Performance. There are no data available.

d. Discussion. The breakwater is an innovative use of surplus material. The pipe and anchor chain, available at scrap metal prices, should provide better protection than the old log breakwater it replaces. The design allowed the owner to do the towing and much of the installation which minimized costs.

5. Friday Harbor, Washington (Port of Friday Harbor).

a. Location. Port of Friday Harbor, Washington (Fig. 17), is a major stopping point for pleasure craft enroute to Canadian waters as well as to cruises in the San Juan Islands. It is also a stop for the Washington State Ferry System, which serves the islands, and is a connection to Vancouver Island (Canada). Fishing vessels also use the harbor.

b. Site Conditions. As shown in Figure 17, there are two windwave exposures--to the southeast with a fetch of about 1 nautical mile and to the northeast with a fetch of about 2 nautical miles. Windspeeds associated with the northeaster that affects the region every few years reach the 50-knot range with gusts to 70 miles per hour and impose the critical design condition for the breakwater because of the longer fetch in that direction. A set of speed-duration curves is shown in Figure 18.

Tide data are as follows:

Highest (30 December 1952):	11.00 feet MLLW
MHHW:	7.70 feet
Mean:	4.75 feet
MLLW:	0.00 foot
Lowest (15 January 1949):	-3.80 feet

Tidal currents are less than 1 knot. Bottom elevations are as follows:

Along inner row of anchors:	-52 feet MLLW
Along main breakwater:	-42 feet
Along inner row of anchors:	-30 feet

Wave heights and periods of 2.9 feet, 2.8 seconds from the northeast and 2.9 feet, 2.4 seconds from the southeast were measured by the U.S. Army Engineer District, Seattle, during an observation period 1969-71. Similar wave measurements were recorded from December 1974 to March 1975 by a University of Washington project. However, neither of these monitoring periods was operational when the critical northeaster occurred. Wakes from boats are a common

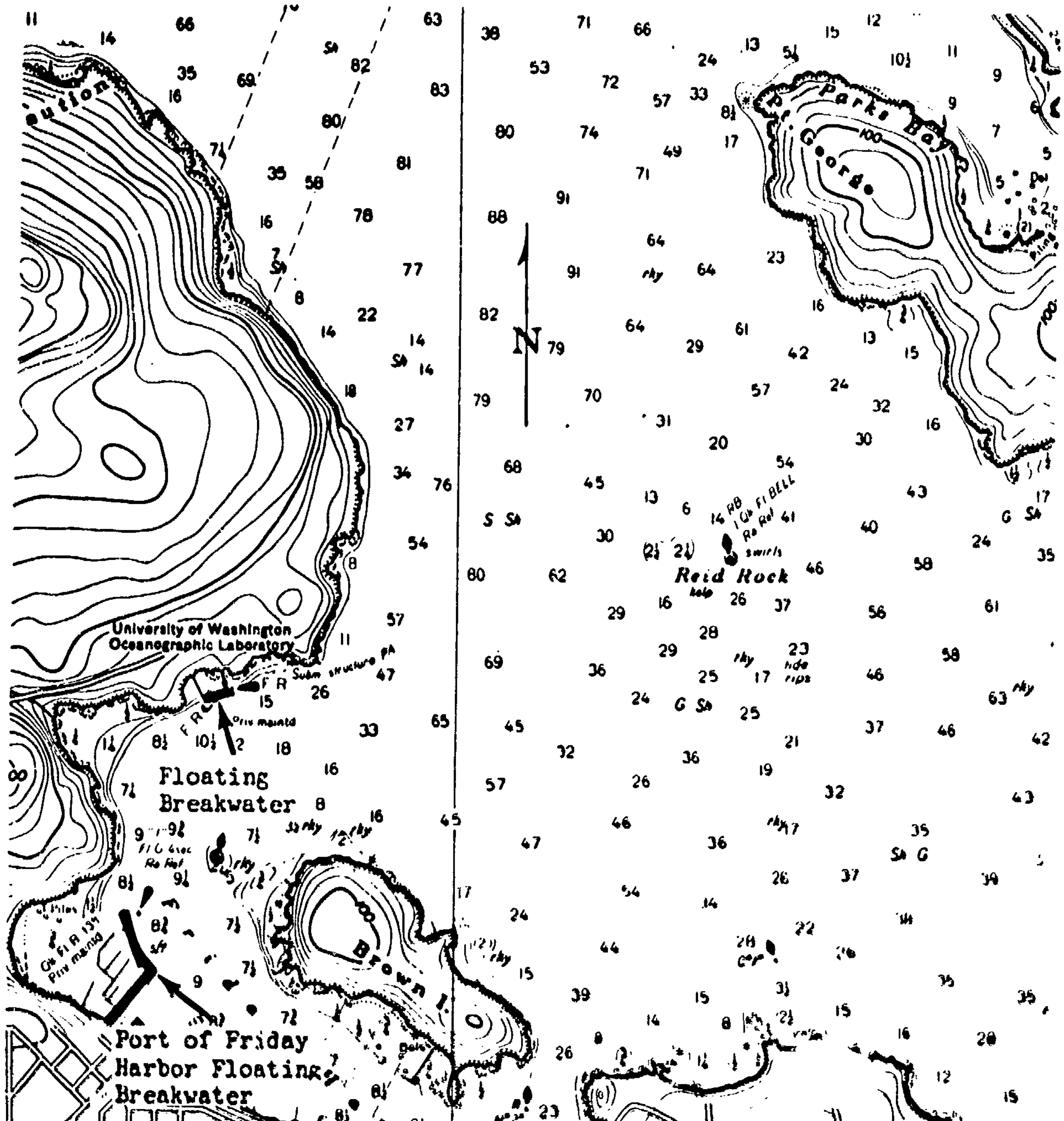


Figure 17. Friday Harbor, Washington (from NOS chart 18425).

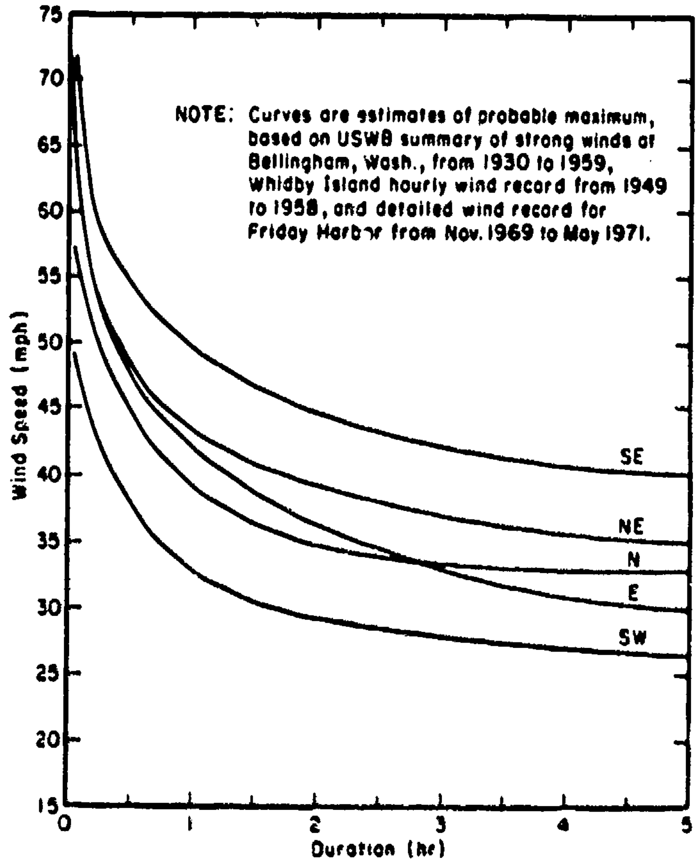


Figure 18. Windspeed-duration curves, Friday Harbor, Washington.

occurrence. Large ferries either approaching or leaving the landing, pass close to the breakwater, while moving at a considerable speed.

c. Breakwater Description.

(1) Design and Installation. The floating breakwater at the Port of Friday Harbor and the one at Tenakee Springs were the first two such structures of major dimension designed for the Pacific Northwest and were installed at about the same time in October 1972. The Friday Harbor structure, a different type than the Alaskan ladder style, uses four rows of polyolefin pontoons about 5 by 5 by 10 feet in overall dimension, linked by a timber matrix to form a 24-foot-wide section drafting about 18 inches. A simplified cross section is shown in Figure 19. The breakwater is laid out in an L-shape to face into the critical wind wave directions. The northeast-facing leg is 627 feet long (see Figs. 20 and 21); the southeast leg is 227 feet long.

The anchor system consists of 18 pairs of anchor lines spaced about 50 feet apart. The lines have three sections, a 32-foot length of 7/8-inch welded alloy chain attached to the breakwater, then a length of braided nylon line, with another length of chain connecting to stake piles. The stake pile system was chosen because of the deep, soft material at the site. The scope of the seaward side is about 1 on 7; the landward side is about 1 on 2.

The installed cost of the floating breakwater was $320 per foot (1972). Those responsible for the breakwater design, construction, and operation are as follows:

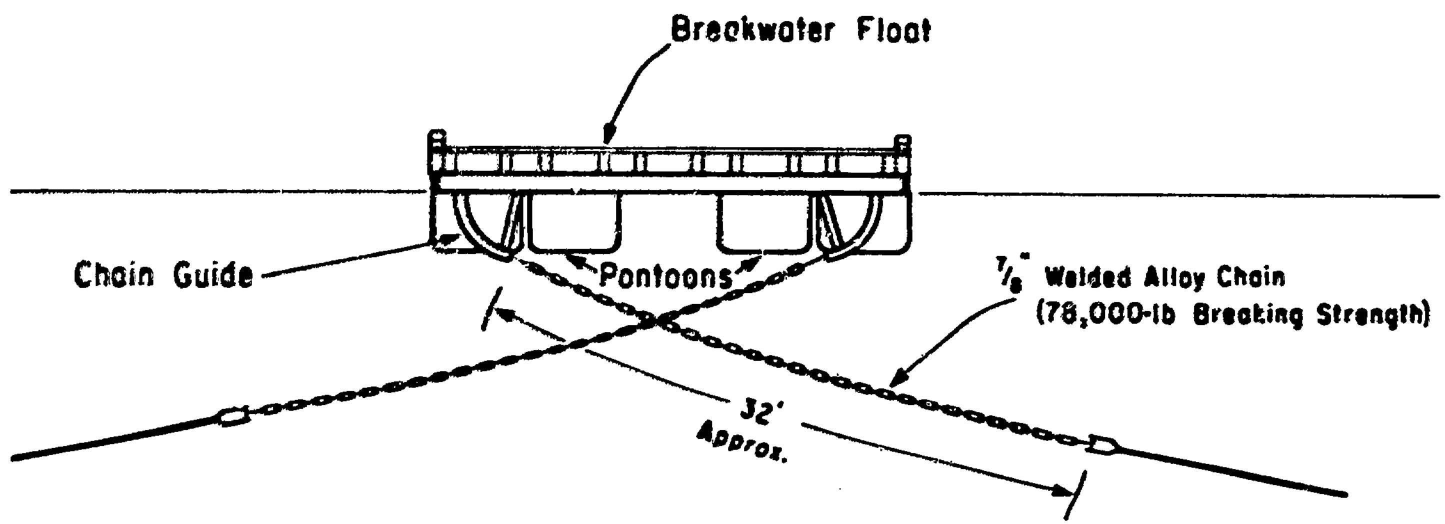


Figure 19. Cross section of Port of Friday Harbor breakwater.

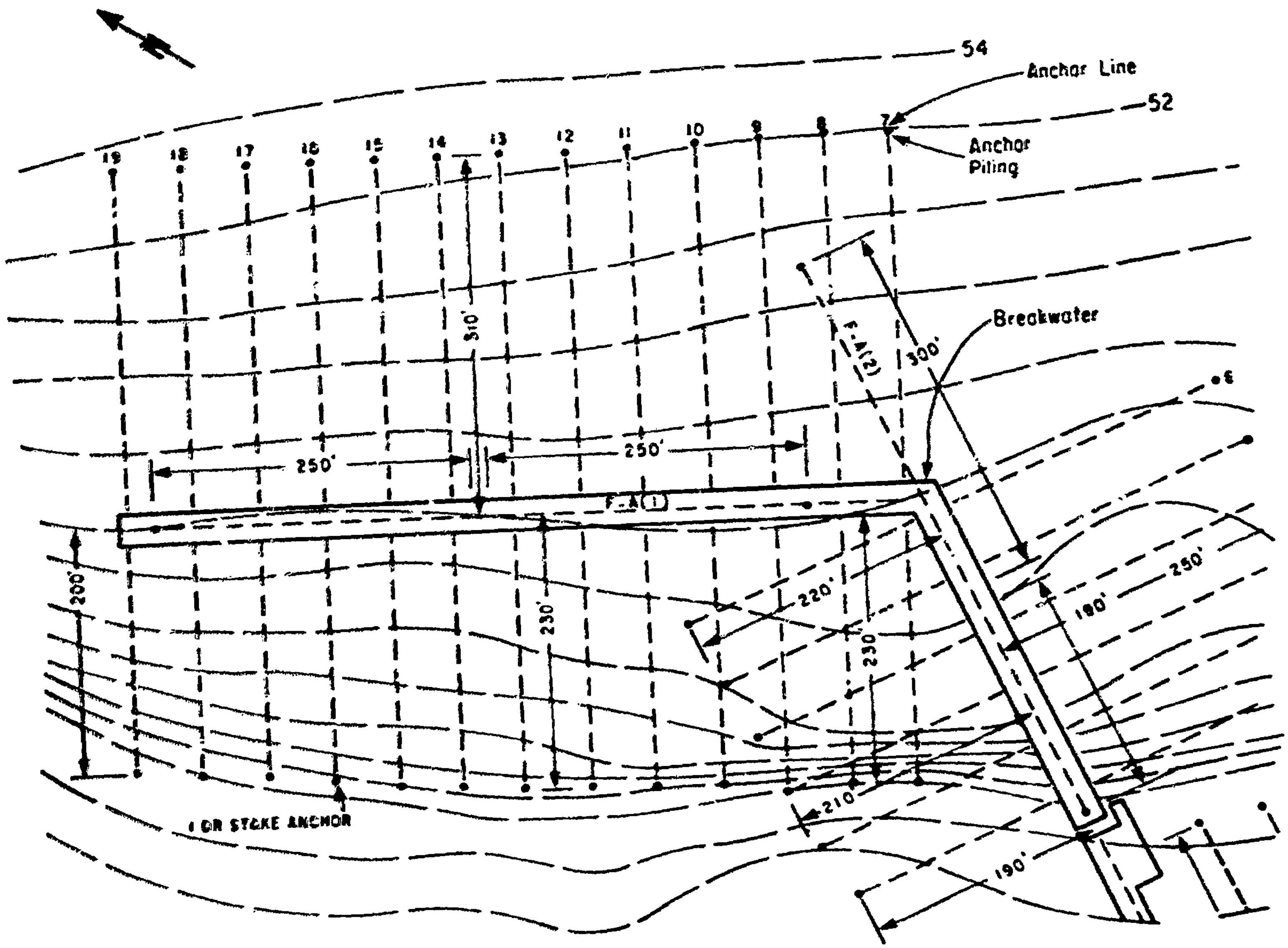
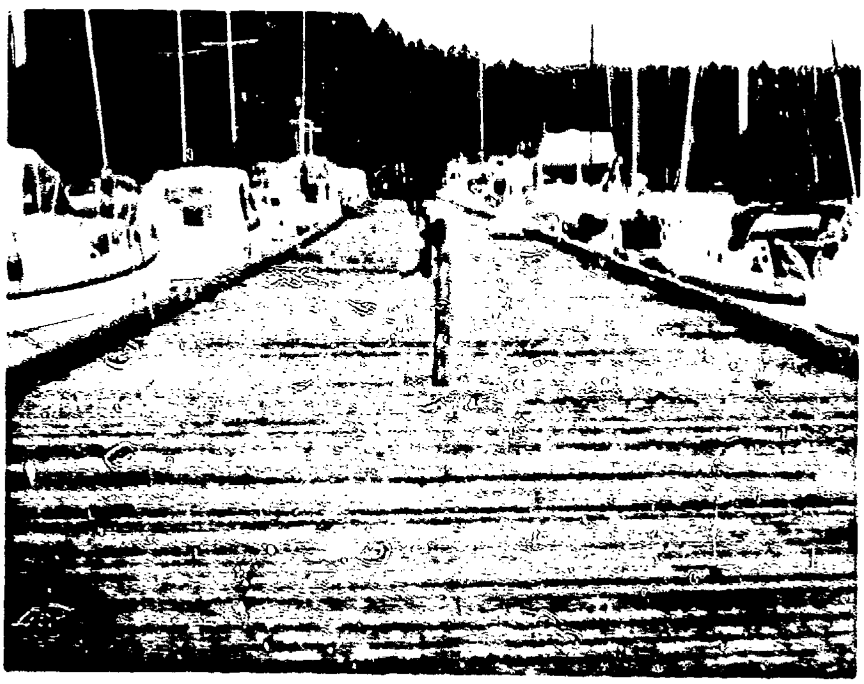


Figure 20. Layout of Port of Friday Harbor breakwater.

a. Dock to floating breakwater.



b. Long leg of floating breakwater.

Figure 21. Photos of Port of Friday Harbor floating breakwater.

Owner-Operator:	Port of Friday Harbor Friday Harbor, Washington (Jack Fairweather, harbormaster)
Designer:	Reid, Middleton and Associates Edmonds, Washington
Fabricator:	Polysintering, Inc. (manufactured pontoons) Monroe, Washington
Installer:	American Pile Driving Co., Inc. (assembled breakwater) Everett, Washington

The breakwater was assembled in Everett, Washington, and towed to the site.

(2) Performance. Boat wake seems to cause as much concern as wind wave transmission. This response is not surprising, since the boating activity occurs more often in the milder seasons. Wind wave transmission on the order of 1 foot is considered tolerable.

Maintenance costs have been high. The structure was damaged extensively in a storm on 7 December 1972, barely 2 months after the installation; 34 of the pontoons cracked and came loose from the structure (21 on the outer row, 12 on the second row, and 1 on the third row), causing it to lose buoyancy. The failures were due to material fatigue where the pontoons were supported by the timber structure. Other pontoons have failed from similar causes. Recent replacements have been with castings of Marlex plastic which have not shown any sign of distress. Fifteen pontoons were replaced in the spring of 1980 at a unit cost of $1,000.

Plans are underway for an enlarged harbor and replacement breakwater of the concrete caisson type. The new breakwater is being designed by the U.S. Army Engineer District, Seattle, and, if authorized, will be constructed by the Corps of Engineers under Section 107 of the 1960 River and Harbor Act. University of Washington is reviewing the design.

d. Discussion. The performance of the breakwater has been less than hoped for by the users. The main problems were associated with a design configuration that relied on a material and fabrication technique which did not produce the expected fatigue-resistant characteristics. There was a push to get the breakwater into place and producing income, which overtightened the design-construction schedule for such a novel and innovative concept. If the proposed harbor expansion is authorized, the existing breakwater can be put to good use for facilities within the harbor.

6. Friday Harbor, Washington (University of Washington Oceanographic Laboratory).

a. Location. The University of Washington Oceanographic Laboratory breakwater is about a half mile north of the Port of Friday Harbor (Fig. 19). The site is open to the east for about 3.5 nautical miles. The breakwater was constructed to allow the marine-related activities in the research programs to be operational year round.

b. Site Conditions. Tide data are the same as Port of Friday Harbor. The breakwater was designed for a 1.5-knot current.

The design parameters were 46-knot wind, fetch-limited, significant wave height of 3.0 feet, period of 3.5 seconds, current of 1.5 knots. Boat wakes are common.

c. Breakwater Description.

(1) Design and Installation. The breakwater is a reinforced concrete caisson cast over a polystyrene foam core with a cross section 4.5 by 15 feet with an 18-inch freeboard and is L-shaped with two 130-foot sections on the long leg parallel to the shore, and one similar section on the short leg (see Fig. 22). The anchor system is laid out to maintain about a 6-foot space between the sections to avoid linkage problems. Short gangways provide access between units. The breakwaters are used as staging areas to handle nets and other gear, and also to provide a protected mooring area. The surface of the units was left rough for good footing.

The anchor system consists of two anchor lines of 1-inch stud-link chain at each end of each section, with one line to the outside at 45° to the breakwater, and the second at the same angle to the inside.

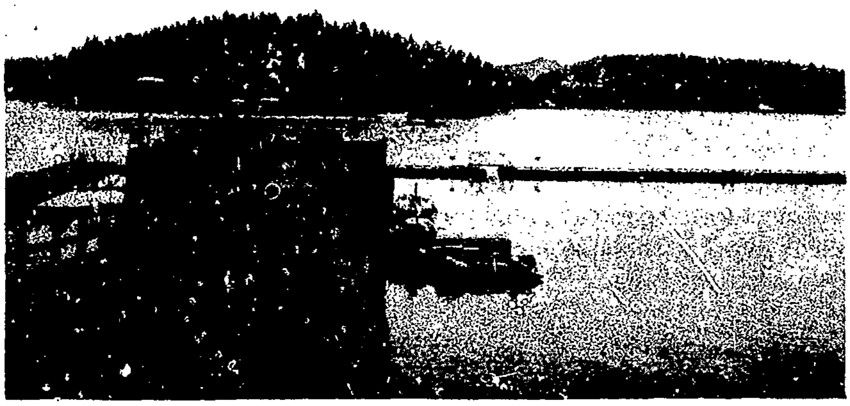
The bottom conditions at the site, a shallow covering of rock, led to restraint supplied by attaching clump weights to the anchor lines. These were concrete blocks 4.5 by 4.5 by 3 feet. The main anchors were concrete blocks 8 by 8 by 6 feet.

The breakwater was installed in 1979 at a cost of $790 per foot. Those responsible for the breakwater design and operation are as follows:

Owner-Operator:	University of Washington Oceanographic Laboratory Friday Harbor, Washington
Designer:	ABAM Engineers 1127 Port of Tacoma Road Tacoma, Washington

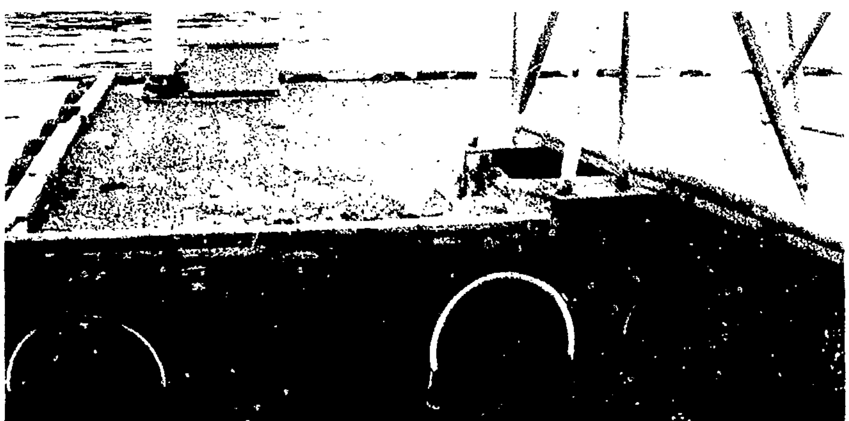
(2) Performance. The users are satisfied with the breakwater performance which has made possible the desired year-round operation of the laboratory activities. The roughened surface provides good footing, but is hard to clean. An unforeseen benefit from the view of the marine biologist is that the breakwater has attracted marine growths and animals distinctly different from those around the Port of Friday Harbor breakwater, only a few hundred yards distant.

Some adjustments in the breakwater were necessary after installation. The gangways between the sections had to be redesigned to provide greater freedom of movement to avoid being overstressed. One of the sections did not



a. Access ramp to floating breakwater.

b. Gangway between sections.



c. Bull rail detail.

Figure 22. Photos of University of Washington Oceanographic Laboratory, Friday Harbor.

float with the required uniform freeboard and had to be ballasted with Styrofoam billets. Presumably, a form slipped during casting, resulting in a heavier and nonuniform unit.

The 2- by 4-inch tie piece on the bull rail is too light for its purpose and has broken in a few places. This member should be at least 4 by 4 inches. The installation of the anchors required extra, expensive site preparation which might have been avoided with more informative foundation surveys and better matching of anchor type to bottom conditions. No special maintenance problems have developed.

d. Discussion. The breakwater type is very appropriate for the site and has met the users' expectations.

7. Blaine, Washington.

a. Location. Semiahmoo Spit Marina is located in Drayton Harbor (see Fig. 23) at Blaine, Washington.

b. Site Conditions. Drayton Harbor (Fig. 23) is quite shallow; the marina site had to be dredged to -10 feet MLLW. The site is exposed only to the southerly quadrant, with a high tide fetch of 1.5 nautical miles to the south and 2 nautical miles to the southeast.

Tide data include a mean range of 5.9 feet and a diurnal range of 9.5 feet. No data are available on tidal currents.

Data on wind waves used for design are not available. The exposure to the south and southeast is likely to experience winds in the more than 40-knot range every winter, with 50-knot speeds on occasion.

c. Breakwater Description.

(1) Design and Installation. The breakwater is of the concrete caisson type cast in 4.5- by 15- by 15-foot units using polystyrene foam blocks as interior formwork and for positive flotation, with a 3-foot draft. The total length of the breakwater, arranged in a U-shape (Fig. 24), will be 3,500 feet. The marina will have 840 slips for pleasure craft and fishing boats.

The units are truck-hauled to the site where four of the units are post-tensioned together to form 60-foot modules, which are then coupled by a chain-rubber fender connector as illustrated in Figure 24.

The anchor system makes use of clump weights on anchor lines consisting of successive length of nylon rope and chain to stake piles, as shown in Figure 25, with a set of lines at each module connection. Figure 26 illustrates the units and connections. Those responsible for the breakwater design, construction, and operation are as follows:

Owner-Operator: Port of Bellingham
P.O. Box 728
Bellingham, Washington

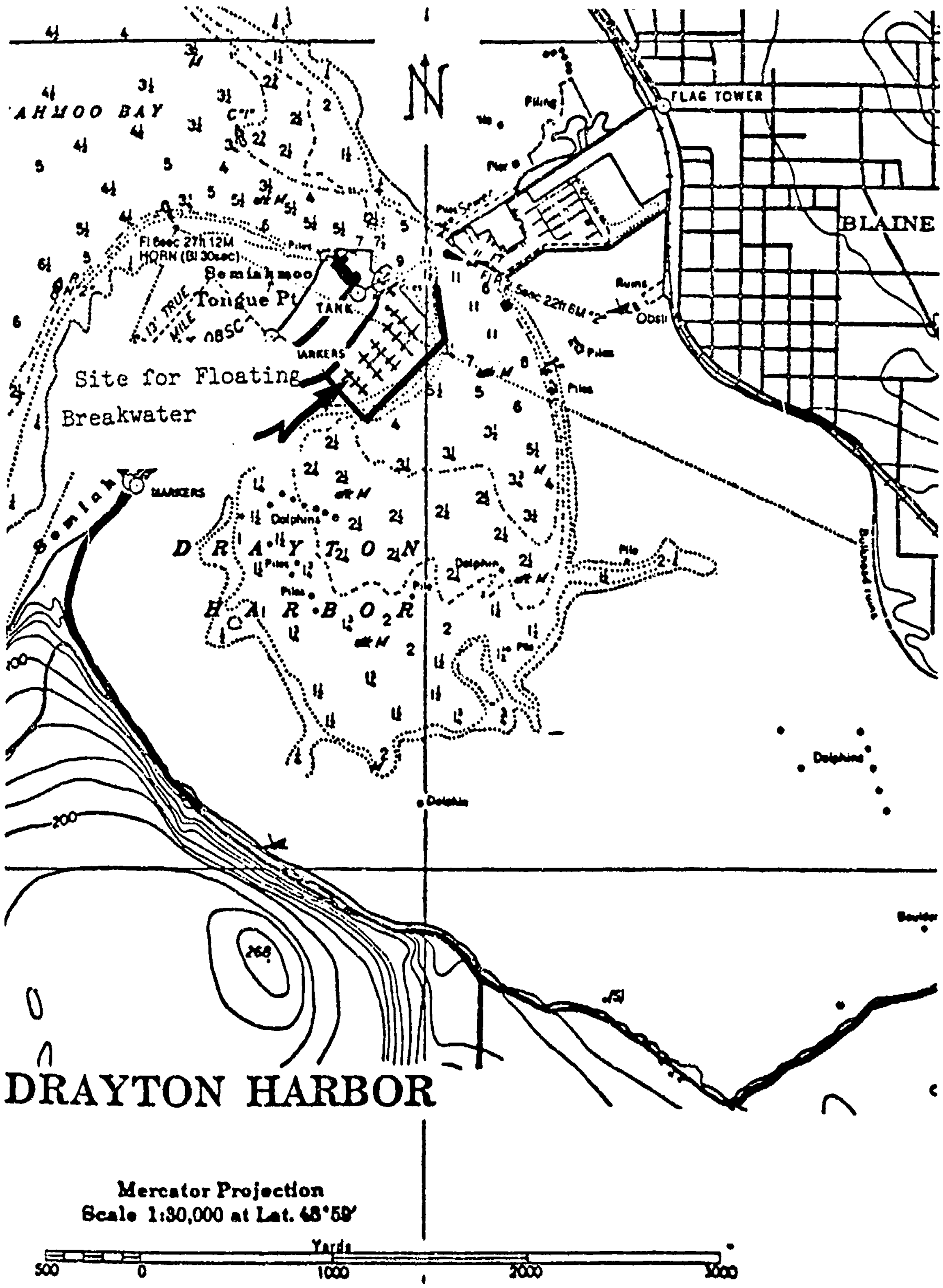


Figure 23. Semiahmoo Spit Marina, Blaine, Washington (from NOS Chart 18421).

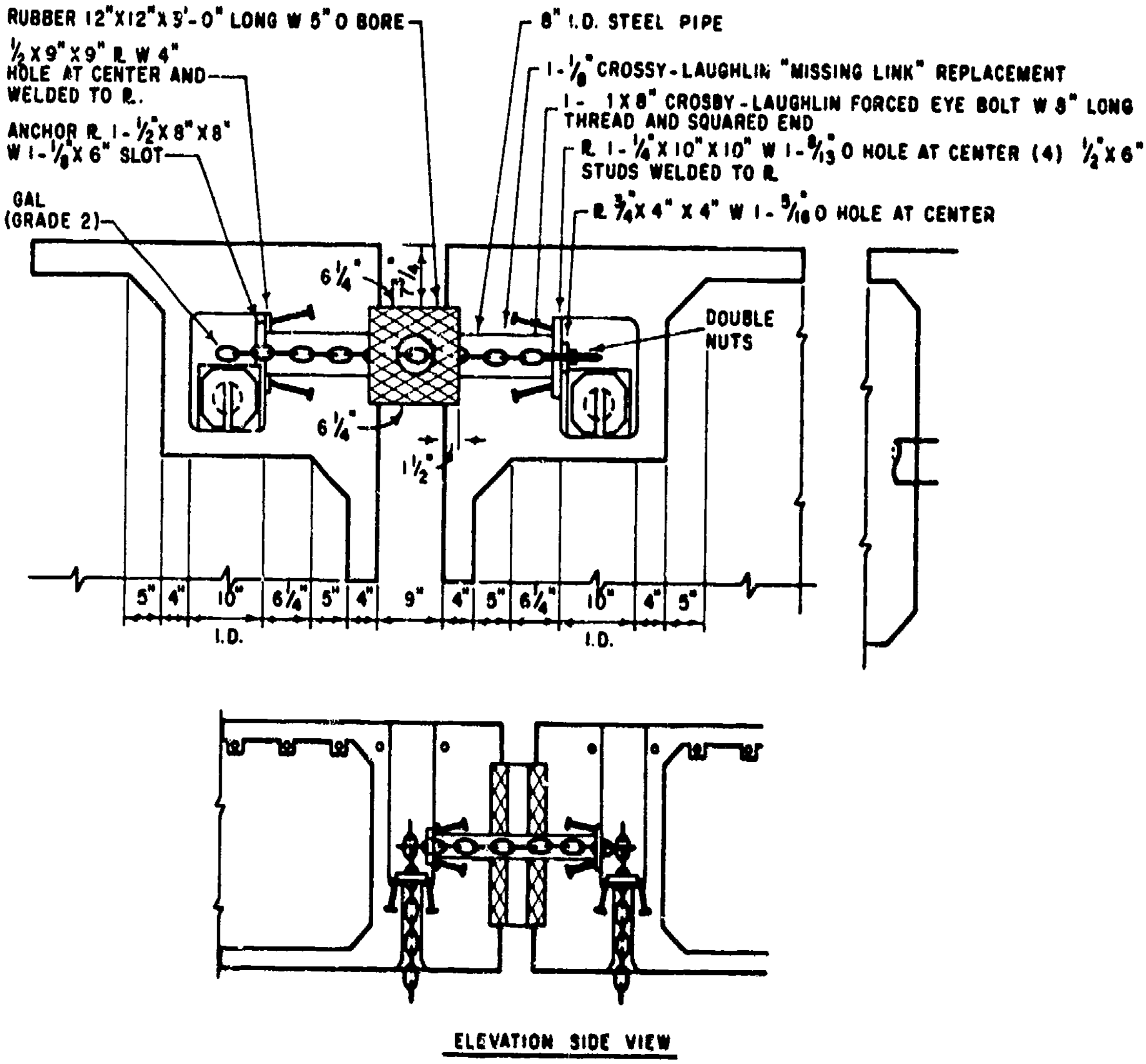


Figure 24. Module connection, Semiahmoo Spit floating breakwater.

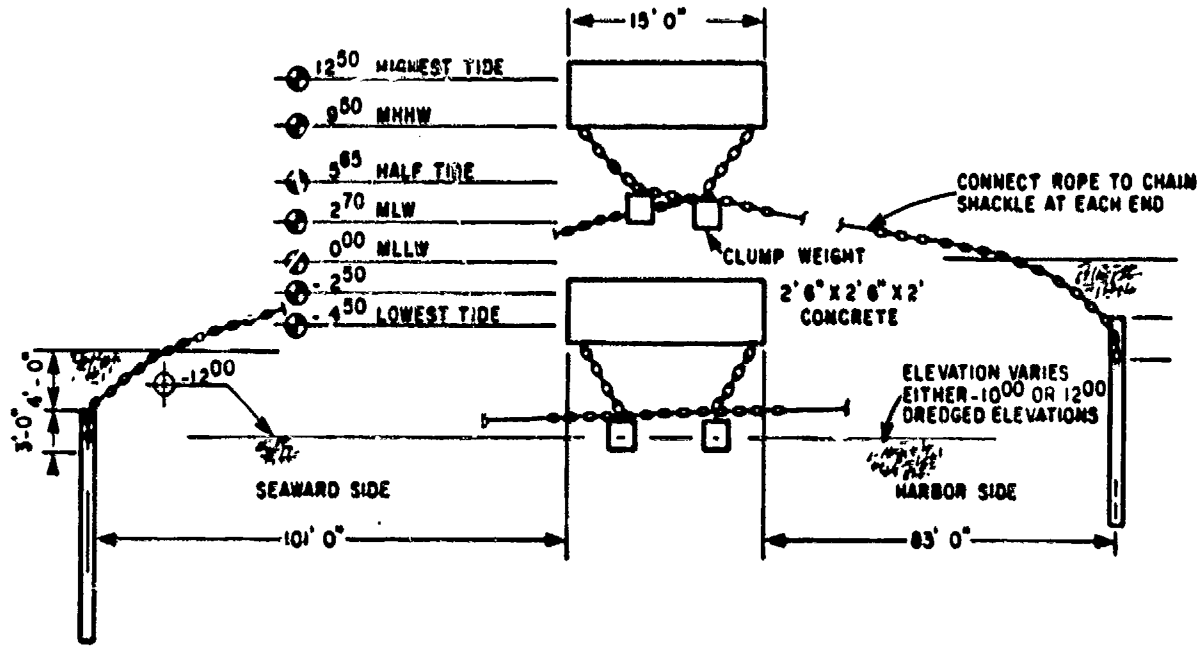


Figure 25. Semiahmoo Spit Marina anchor detail.

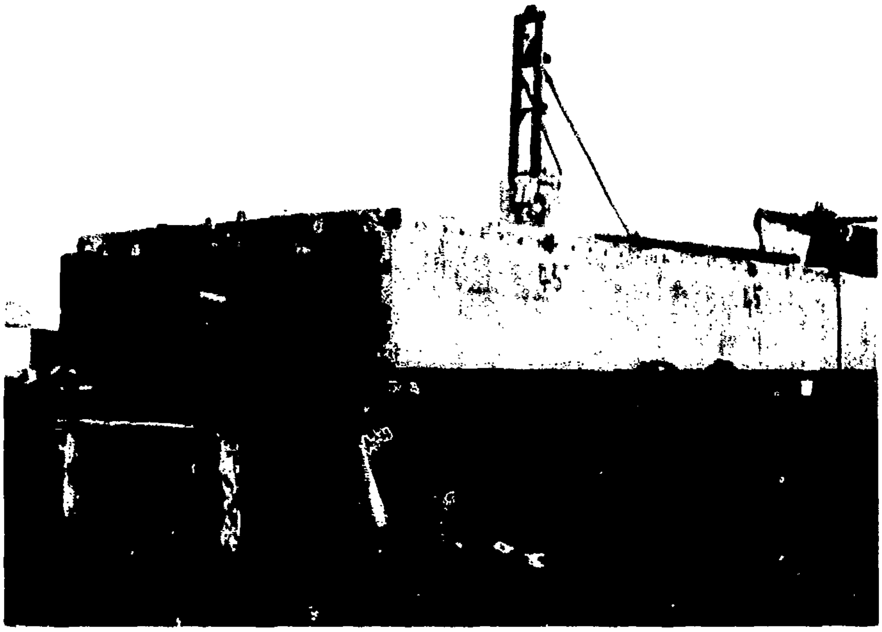


Figure 26. Photos of the module detail of the Semiahmoo breakwater.

Designer: URS
4th and Vine Building
Seattle, Washington

Designer-Fabricator: Bellingham Marine Industries
Bellingham, Washington

(3) Performance. No information is available. The breakwater was under construction in February 1981.

d. Discussion. Module connections have been a source of concern for many floating breakwaters. The design for the Semiahmoo connectors provides for restraint, flexibility, adjustments for maintaining a no-slack connection, and also appears to be easily assembled in the field.

The Semiahmoo site could be a good site for a field measurement program to collect data on breakwater structural, kinematic, and hydraulic responses. The input data would be limited naturally by the shallow-water conditions and probability of storm and high tide coexistence.

8. Langley, Washington.

a. Location. Langley, Washington (Fig. 27), is a small community on the southeast side of Whidbey Island and faces Saratoga Passage.

b. Site Conditions. The fetch is long, 8 to 12 nautical miles to the northwest and about 4 nautical miles to the east-northeast. Wind data specific to the site are not available, but the speed-duration curves for Puget Sound (Fig. 28) should be representative for design purposes.

Tide data, gathered at Tulalip, Washington, include a mean range of 7.6 feet and a diurnal range of 11.2 feet.

c. Breakwater Description.

(1) Design and Installation. The breakwater is the Goodyear module floating tire type, composed of tire groups banded together with belting and nylon bolts, with Styrofoam added to the tire crowns for extra buoyancy. The northwest-facing section has a planform of 52 by 230 feet; the east-facing section is 65 by 216 feet. Figure 29 is an east-facing view of the installation. The breakwater is anchored by cables fastened to piling.

Those responsible for the breakwater design and operation are as follows:

Owner-Operator: Port of Whidbey Island

Designer: Parametrix, Inc.
Everett, Washington

(2) Performance. The breakwater reduces the short-crested waves satisfactorily, but transmits too much energy in the lower frequencies. Connections in the boat slips were overstressed, and boats have not been permitted to use them. The slips were removed for the 1980-81 winter season. The north end of the east breakwater has been sinking, possibly due to the combination

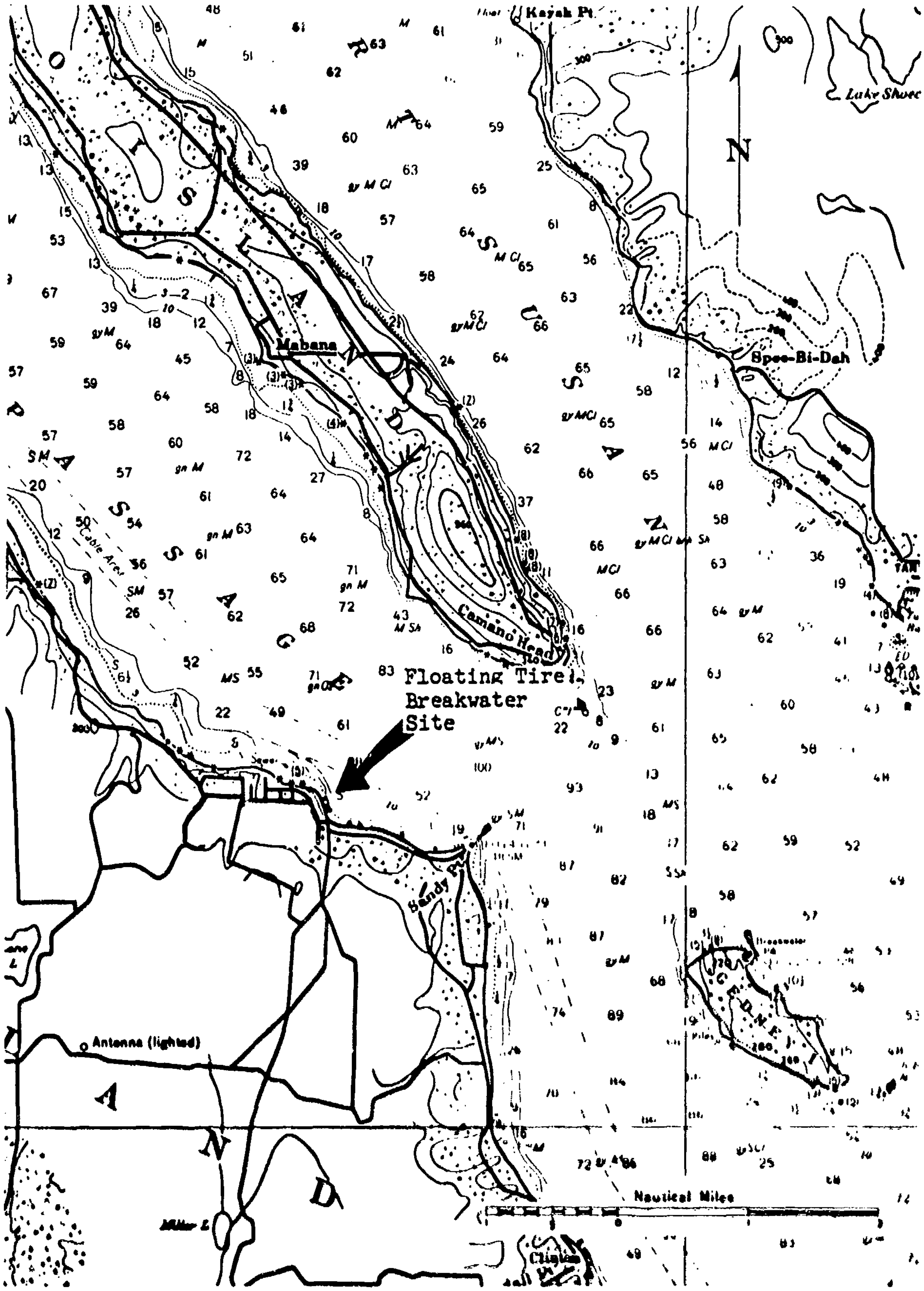


Figure 27. Floating tire breakwater, Langley, Washington (from NOS chart 18441).

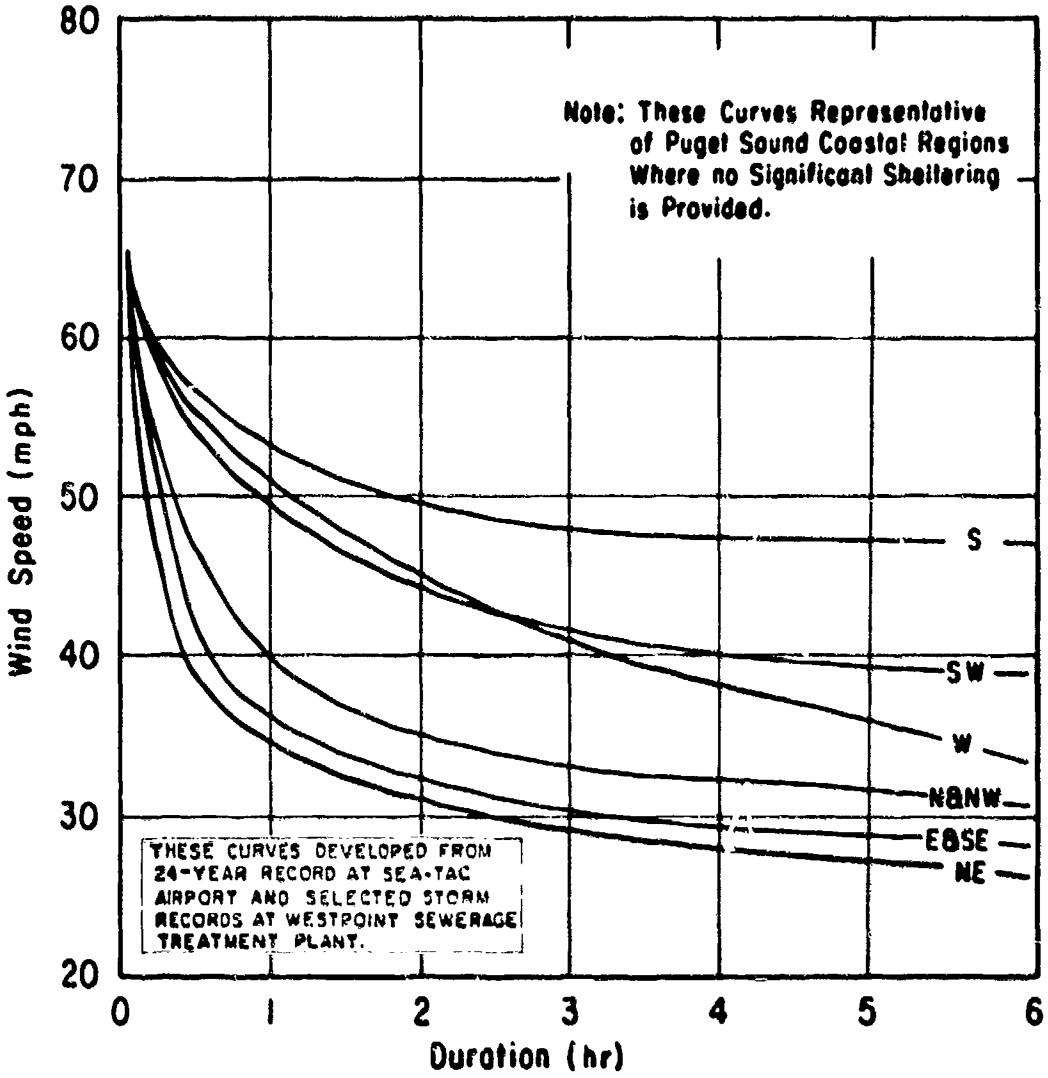


Figure 28. Windspeed-duration curves, Puget Sound.

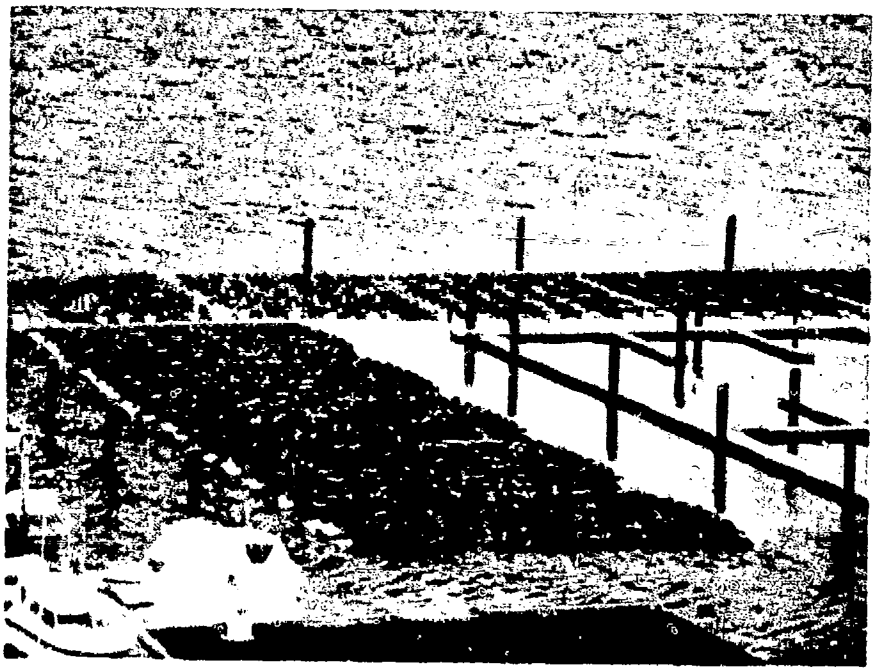


Figure 29. Photo of floating tire breakwater, Langley, Washington.

of current drag and loss of buoyancy. Reports on other Styrofoam-filled tire breakwaters state that the foam breaks down under the continuous flexure experienced in the wind wave exposure.

The owner-operator is not satisfied with the performance of the breakwater.

d. Discussion. The site, with its long fetch up Saratoga Passage and the frequency of winds from that direction, experiences more severe conditions than are appropriate for the type of breakwater installed.

9. Everett, Washington.

a. Location. The breakwater is at a large small-craft harbor that lies along a waterway in the Port of Everett (Fig. 30). The waterway is only about 800 feet wide; thus, the breakwater serves primarily to protect the harbor from boat wake.

b. Site Conditions. Tide data include a mean range of 7.4 feet and a diurnal range of 11.1 feet. Tidal currents are estimated at 1 to 2 knots.

c. Breakwater Description.

(1) Design and Installation. The breakwater is of the concrete caisson-type cast over a Styrofoam core having a cross section 3 by 10 feet and draft of 1.5 feet. The north section (see Figs. 30 and 31) is 530 feet long; the south section is 860 feet long.

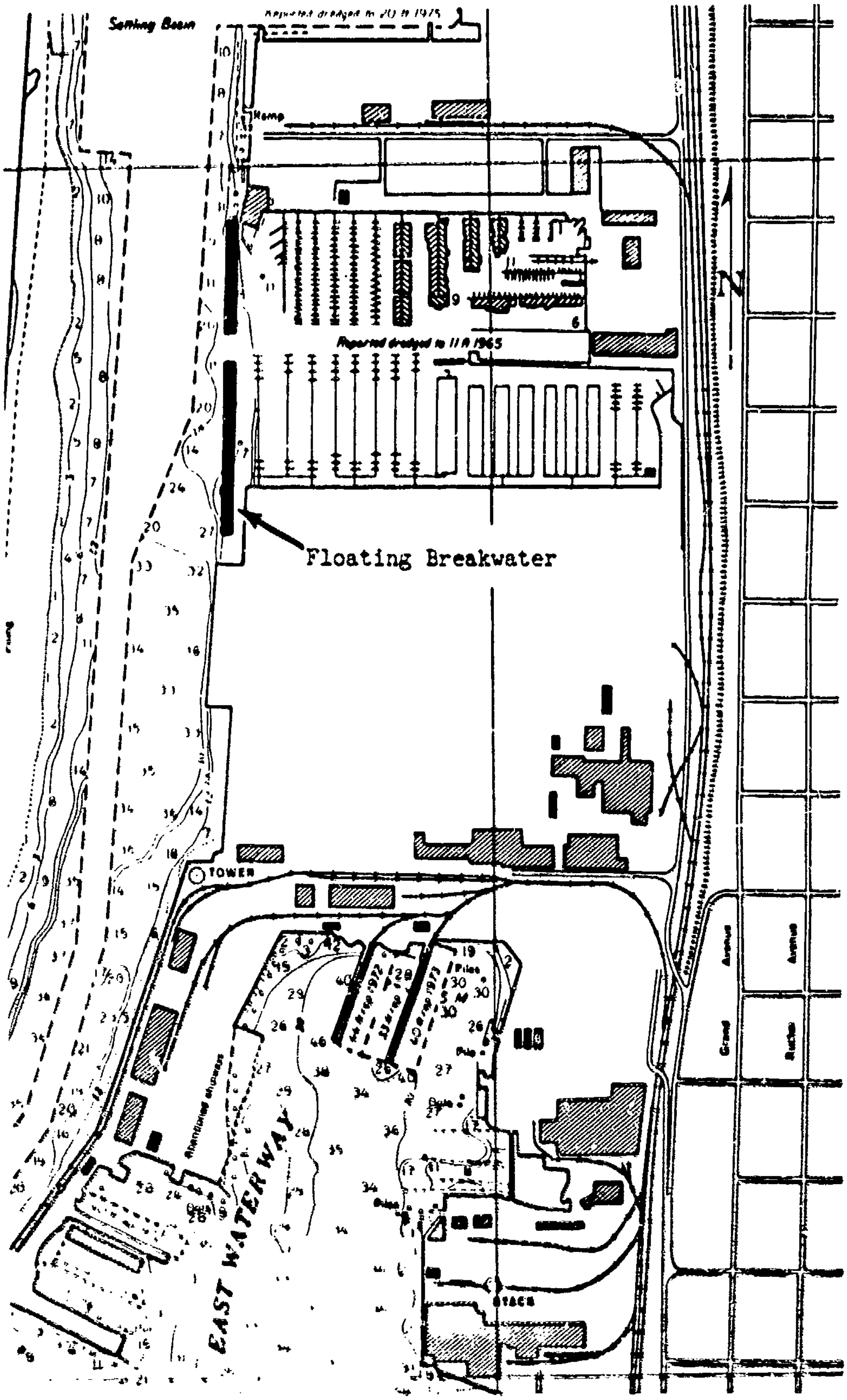
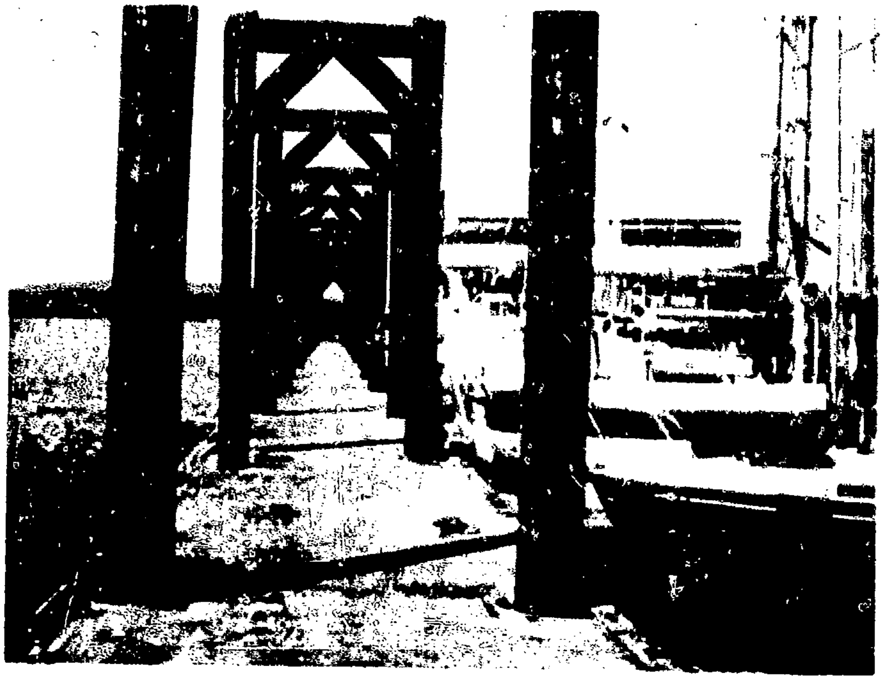
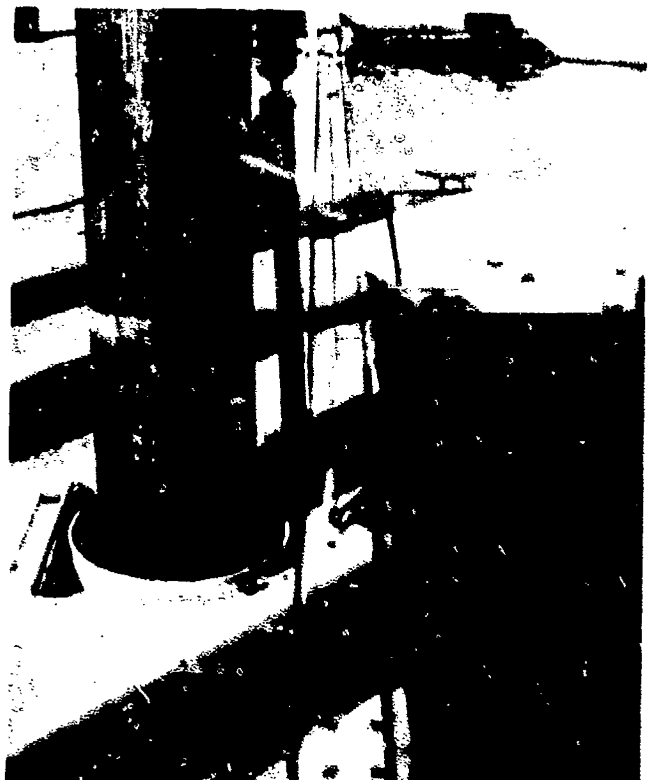


Figure 30. Port of Everett, Washington, floating breakwater site.



a. Pile bent floating breakwater.



b. Ring guide support.

Figure 31. Photos of the floating breakwater at the Port of Everett, Washington.

The breakwater was installed in 1979 at a cost of $273 per foot. The breakwater is anchored by pile bents, as illustrated in Figure 31. Those responsible for the breakwater design, construction, and operation are as follows:

Owner-Operator:	Port of Everett Everett, Washington
Designer:	Reid, Middleton and Associates Edmonds, Washington
Breakwater Designer-Fabricator:	Bellingham Marine Industries Bellingham, Washington

(2) Performance. The breakwater has performed favorably. The boat channel is easy to keep under surveillance, so boat speeds are held in check.

10. Port Orchard, Washington.

a. Location. Port Orchard (Fig. 32) lies across Sinclair Inlet from Bremerton, Washington.

b. Site Conditions. The prevailing winds in the area are from the south, so the harbor site is well shielded from that direction. The main exposures are to the southwest and the northeast with fetches 1.5 and 4 nautical miles, respectively. The windspeed-duration curves in Figure 28 are the best available data.

Tide data are as follows:

Highest (estimated):	14.7 feet MLLW
MHHW:	11.7 feet
Mean:	6.8 feet
MLLW:	0.0 foot
Lowest (estimated):	4.5 feet

Tidal currents are less than 1 knot.

c. Breakwater Description.

(1) Design and Installation. The breakwater is laid out in two sections, as shown in Figures 32 and 33. The L-shaped section is 1,500 feet long and composed of lightweight, reinforced concrete pontoons cast over solid Styrofoam core units 3 by 12 feet and 20 feet long, with a draft of 1.8 feet. Three of these pontoons were posttensioned together to form 63-foot modules which were then joined with the connectors shown schematically in Figure 34; four connectors were used at each joint. The west section is of similar construction but the units are 3 by 8 by 12 feet and connected by wooden walers for a length of 320 feet.

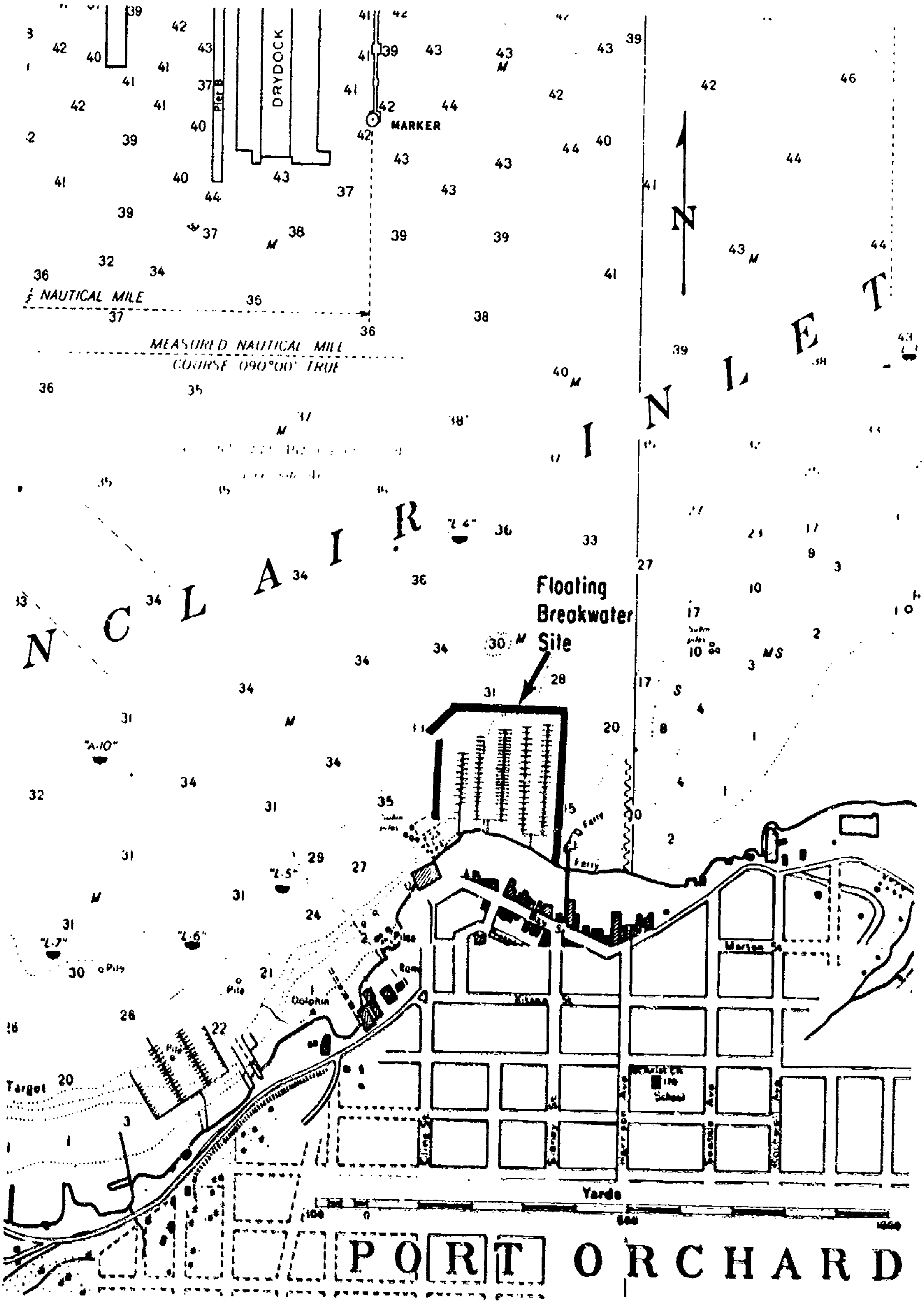


Figure 32. Port Orchard floating breakwater site (from NOS chart 18452).

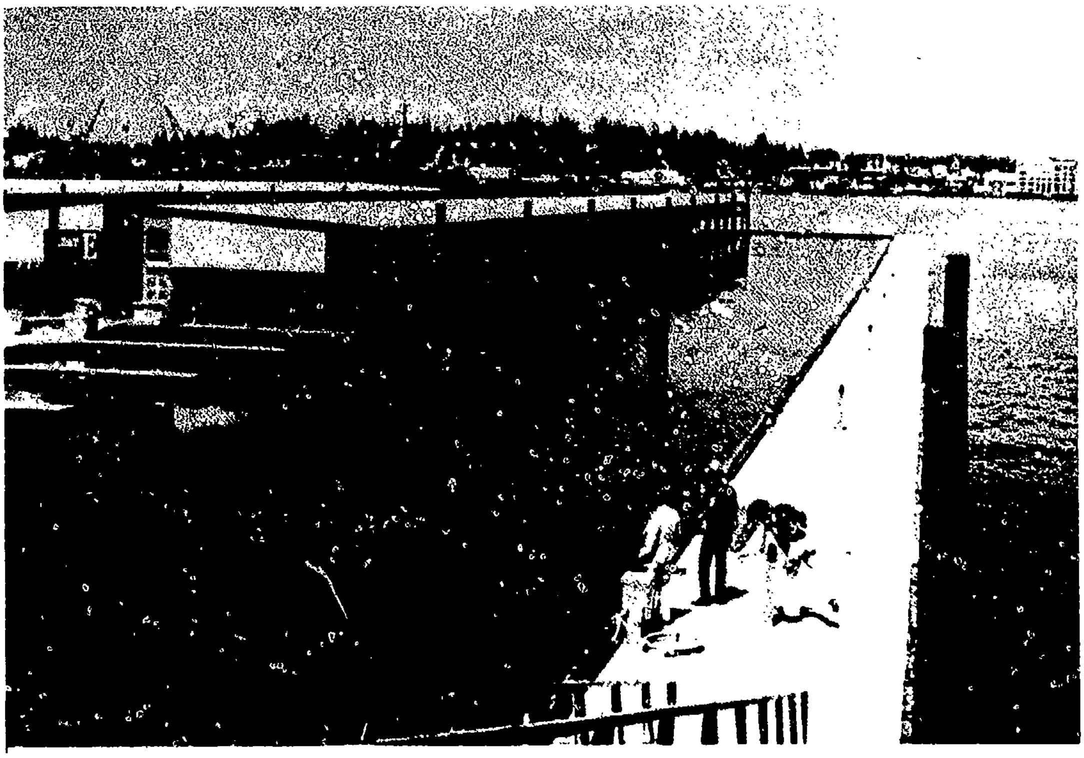


Figure 33. Floating breakwater and marina, Port Orchard, Washington.

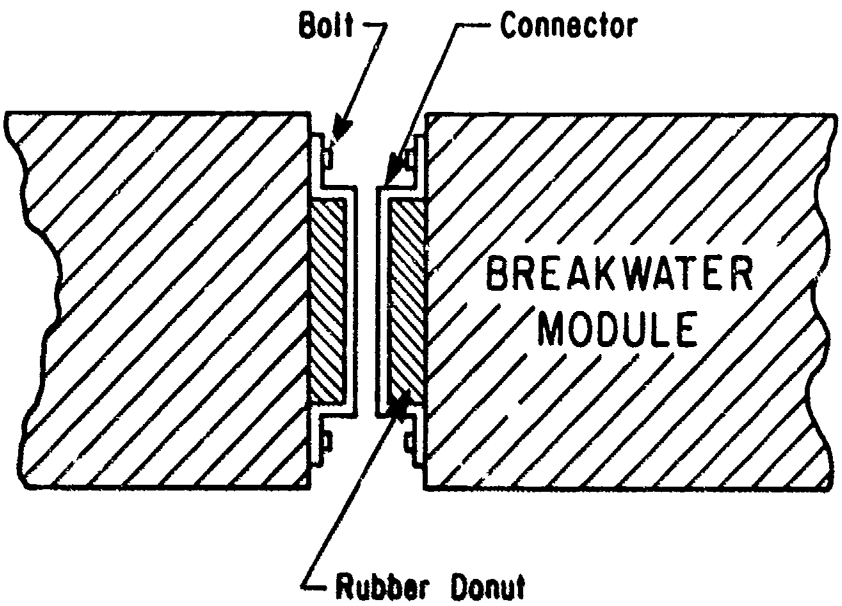


Figure 34. Schematic drawing of module connection, Port Orchard floating breakwater.

The L-shaped section is anchored by a composite 24-inch anchor line of 3/8-inch welded alloy chain, braided nylon line and a lower length of chain fastened to stake piles. The chains cross beneath the breakwater to provide as much clearance as possible close to the breakwater. The west section is restrained by pile bents. A deep, soft muck is the typical foundation material at the site.

Those responsible for the breakwater design, construction, and operation are as follows:

Owner/Operator:	Port of Bremerton Bremerton, Washington
Designer:	Reid, Middleton and Associates Edmonds, Washington
Fabricator:	Bellingham Marine Industries Bellingham, Washington

(2) Performance. The management and boat owners expressed satisfaction with the breakwater. Storm damage has been handled well since installation, with the exception of the western section which has been hit by two storms with reported significant wave heights of 4 feet—well in excess of design values. When the waves incident to the west breakwater exceed heights of about 2 feet, there is a greater transmission than desired, but this is not a severe problem.

The north breakwater has performed very well. One connection failure was probably due to a faulty fabrication detail; it was successfully repaired. All the anchor chains have corroded badly and are being replaced. The original ones were made of 3/8-inch chain, with no cathodic protection; the replacements are of 1/2-inch chain, with zinc anode sacrificial blocks 2 by 2 by 30 inches with two placed on each anchor line. The cost of the anchor line repair is estimated at $30,000. Figure 35 illustrates the piling and chain connections.

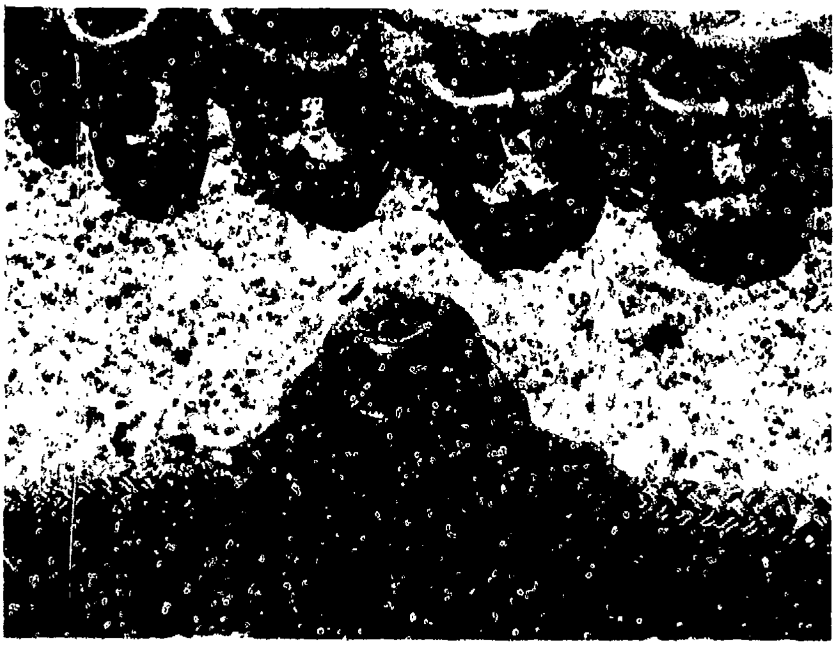
Some of the anchor piles have been attacked by marine borers. Replacements will be cut off below the mudline, to be out of reach of these borers. There is only a small area of concrete spalling in the center of two pontoons.

d. Discussion. The west breakwater was apparently underdesigned for the wave climate that develops from the west. Other design aspects have worked out well, except for the anchor chains. The new design with both a heavier chain and cathodic protection should ensure a much longer life than the 6 years for the initial system. Boat wake from the larger vessels passes through the breakwater, but users appear to have adapted to this inconvenience.

11. Camas-Washougal, Washington.

a. Location. The breakwater at Port of Camas-Washougal, about 20 miles east of Vancouver, Washington (Figs. 36 and 37), parallels the north shore of the Columbia River, and serves to protect a marina catering largely to pleasure craft.

a. Weakened anchor pile.



b. Corroded anchor chain with nylon anchor line.

c. Replacement anchor line.

Figure 35. Photos of anchor chains at the Port Orchard floating breakwater.

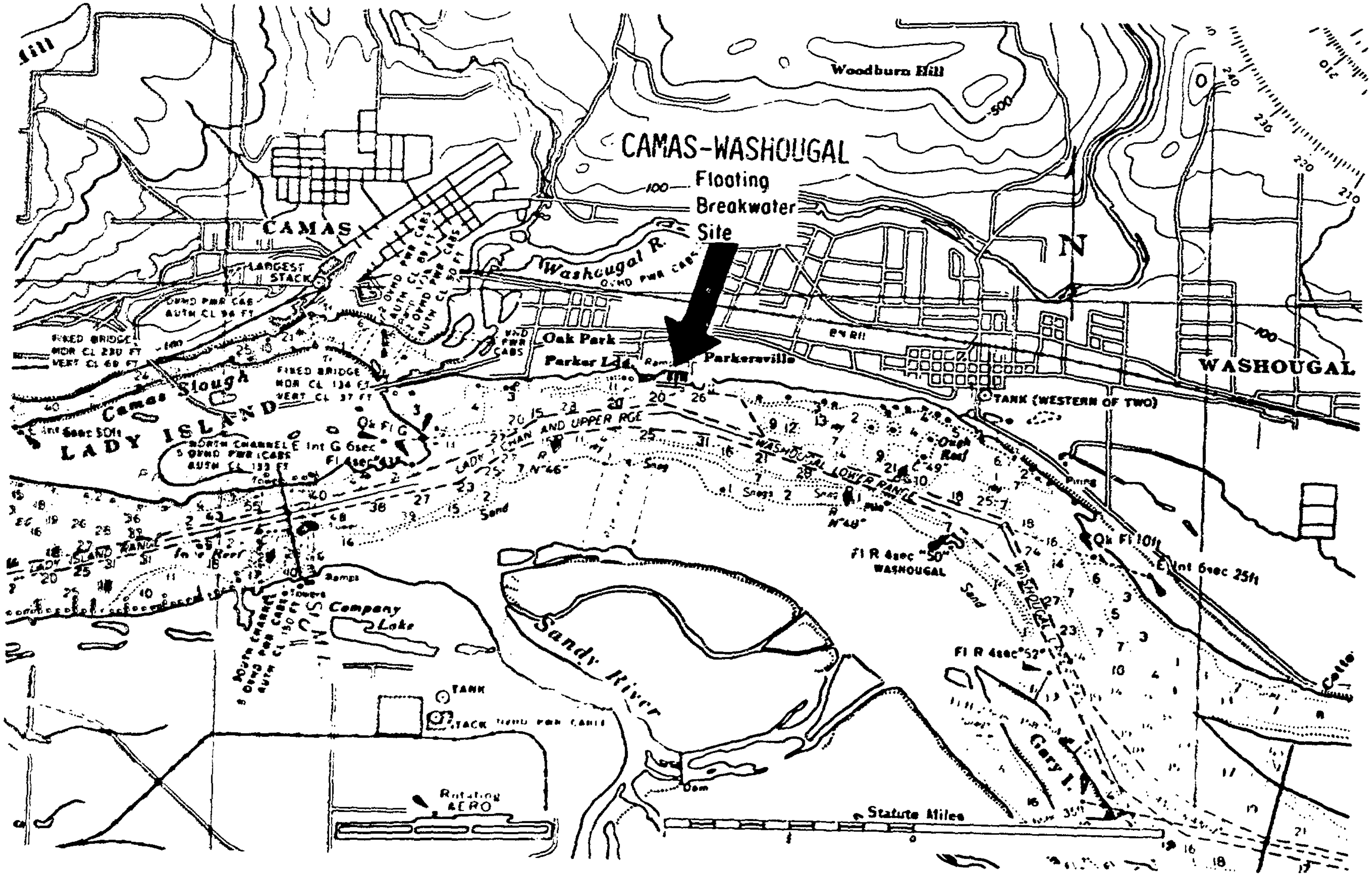


Figure 36. Camas-Washougal floating breakwater (from NOS chart 18531).

a. Floating breakwater section.

b. Debris barrier and main floating breakwater.

Figure 37. Photos of the Port of Camas-Washougal floating breakwater.

b. Site Conditions. The important winds come downriver from the east where the fetch is about 1.9 miles. No tidal current measurements have been made at the site, but speeds of 3 to 4 knots have been estimated, with higher speeds possible during periods of peak flood flows.

Winds blowing down the Columbia River develop waves that break and pass over the top of the breakwater, but have not caused problems with moored boats.

c. Breakwater Design.

(1) Design and Installation. The breakwater is a caisson-type structure constructed of lightweight, reinforced concrete cast over Styrofoam blocks in units 3 by 10 feet in the cross section and 12 feet long, drafting about 18 inches. The units are held together with timber walers. The main section parallel to the shore (and river) is 1,073 feet long, and is held by guide pile dolphins spaced about 84 feet apart (Fig. 38). A 233-foot section of breakwater is set at about a 45° angle to the upstream end of the main breakwater to serve as a trash deflector (Fig. 37,b). The breakwater is designed to provide transient moorage and public access with special fishing facilities provided. It was installed in early 1979. Those responsible for the breakwater design, construction, and installation are as follows:

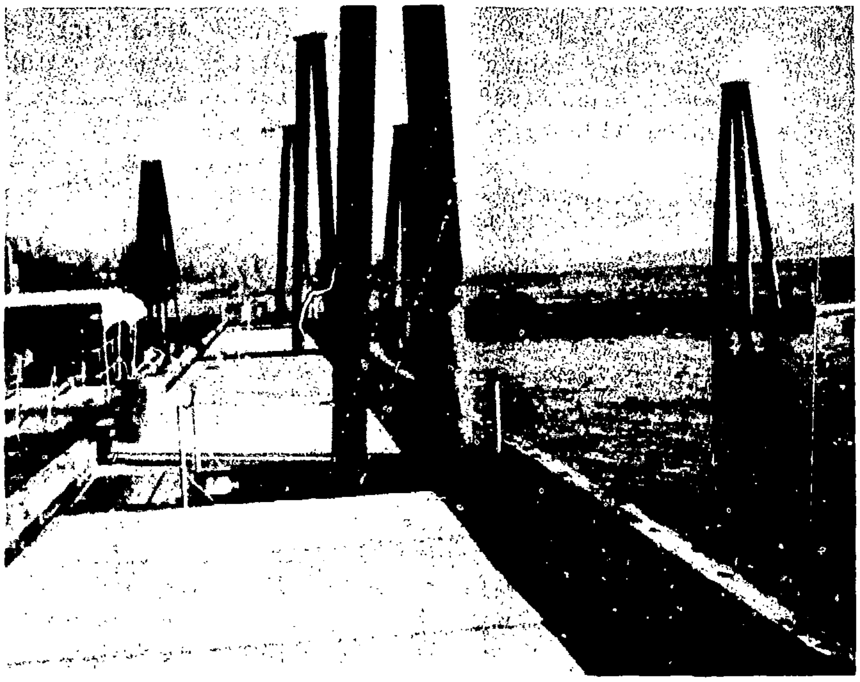
Owner-Operator:	Port of Camas-Washougal, Washington
Project Designer:	Parametrix, Inc. Vancouver, Washington
Breakwater Designer-Fabricator:	Bellingham Marine Industries Bellingham, Washington

(2) Performance. The wind waves move nearly parallel to the breakwater, so they are effectively attenuated. The only problem reported is that from the boat wake generated by vessels passing close to the breakwater at high speeds. The trash deflector is not effective. Logs tend to jam up on it and then work underneath it and move into the marina. The river current keeps the breakwater snugged up against the pile restraints.

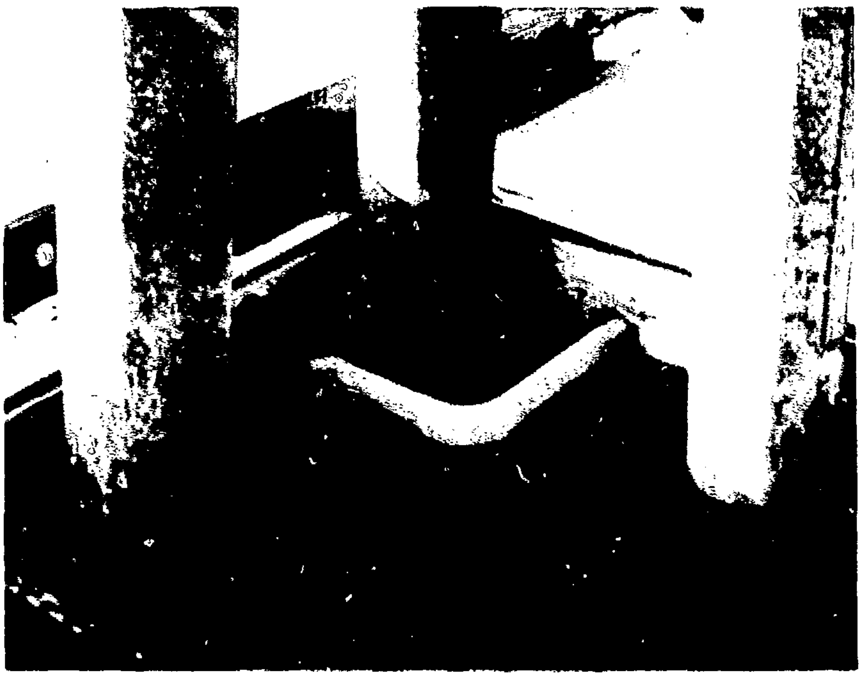
d. Discussion. The overall system seems to be performing very well, and the owner is satisfied. This site could serve as a field monitoring station for forces on pile-restrained breakwaters, although the river current would be an ever-present additive to the wave loadings from wind or boat.

III. SUMMARY AND CONCLUSIONS

One of the more perplexing problems facing the designer for a floating breakwater is the specification of a realistic wave climate. Local data are rarely available and contemporary methods of developing an appropriate design spectra for the variable fetch conditions usually encountered at potential floating breakwater sites leave much subjective freedom in specifying principal prameters. Hopefully, the two-dimensional wave models being developed will narrow the present zone of uncertainty.



a. Upstream view.



b. Guide pile detail.

Figure 38. Photos of the main section of the Port of Camas-Washougal floating breakwater.

At some sites, boat wake loadings may be more important than those from the wind-generated waves. Better models depicting wake loadings are needed. The floating breakwater transmission characteristics are sensitive to the wake from certain hull-speed distance-orientation cases.

The recently developed analytical methods treating the floating breakwater as a dynamic system are an improvement over static methods, but field data are still needed to refine the values of the various coefficients in the analyses and to verify the general methodology. Possible field installations should be screened as potential field measurement sites. The system being fabricated for Semiahmoo Spit Marina, Blaine, Washington, looks promising because the exposure is such that frequent winds of the 30- to 50-knot range should occur most of the winter season. The water depth is shallow, which will restrict wave buildup.

The users of the floating breakwaters of the concrete caisson or ladder (Alaskan) type seem to be quite satisfied with their effectiveness and maintenance costs. Some of this satisfaction is likely attributable to an adjustment in expectation of what can be accomplished in reducing wave heights within a given budget, developing adequate mooring techniques, and an awareness of crowded conditions at all moorage sites. The use of this type of breakwater seems to be confined to the western Pacific coast.

Tenakee Springs, installed in 1973, followed by Sitka and Port Orchard (installed in 1974), are the sites with the longest history of performance for the concrete units. Early problems at Tenakee related to alinement and module connections have been corrected; anchor chains are being replaced at Port Orchard. Present design knowledge would have avoided these two problems. Otherwise, the units have performed very satisfactorily.

The other early breakwater of major dimension (for the area surveyed) was the one at Friday Harbor (installed in 1973), consisting of large plastic flotation tanks with a timber deck. A major storm shortly after installation caused extensive damage. Plans are underway for replacement with a concrete caisson and an enlarged configuration to accommodate the expanding demand for moorages.

The floating tire breakwaters should be restricted to sites where wave conditions are quite mild. Experiences to date show that, when subjected to an active wave climate, there is a rapid deterioration in buoyancy due to breakdown of flotation and fatiguing of the systems used to hold the tires together. Marine growth will also diminish structural buoyancy.

Bottom conditions at a proposed site should be determined carefully to provide a sound basis for specification of anchor type. Extra costs have been incurred at Ketchikan and at the Friday Harbor Oceanographic Laboratory site due to unforeseen foundation conditions.

No damage to anchor systems from wave loadings has been reported. Thorough anchor inspections are difficult because of marine growths and sedimentation. However, there are many instances where an anchor line could be disconnected at the breakwater and be partially exposed for a more detailed look. The one data point on longevity of anchor chain is that from the Port Orchard installation, where a replacement after 6 years has been necessary.

However, the new design with larger chain and cathodic protection is expected to last a long time.

The connections between modules have been the "Achille's Heel" in floating breakwater design. Experience has had to substitute for analysis in evaluating the loadings to be transferred between modules. The recent dynamic structural response modules are expected to provide realistic design values, thereby replacing the costly empirical experience approach. Some design progressions show up in the installations covered in this report. The rubber in the chain-bumper system of the initial Tenakee design took a permanent set and allowed slack to develop. The replacement design eliminated the set problem by connecting the flexible rubber fender rigidly to each module. The connections of the breakwater deck to the flotation modules in the Friday Harbor breakwater invited stress reversals and concentrations with subsequent fatigue failures. The layout of the connections for the Semiahmoo Marina looked like a practical way of providing a resilient, flexible connection well suited to field assembly. Its performance, however, suggests it was underdesigned for the loading imposed by the high winds experienced in the 1981-82 winter. The current design trend for the caisson-type breakwater is to replace the flexible connection by posttensioning modules to form a continuous structure. Although more expensive, fabrication and field assembly procedures are more exacting; therefore, the final product should be cost-effective.

Design data for the pile-restrained breakwater have a rather weak base. Logical assumptions about wave loadings on such piling can lead to forces that do not appear to develop in the field. Dynamic analysis will require the resolution of the interaction between the piling and the breakwater; such a synthesis would be aided greatly by some prototype data. The floating breakwater at Camas-Washougal would be a possible site for field experiments, as would the unit at Everett Harbor. An energy absorbing connection between the pile collar and the breakwater would relieve some of the dynamic load. A suggested design would be concentric annular rings, with the annulus taken up by rubber fendering material.

The pros and cons of lightweight versus regular weight concrete may have been resolved by market conditions. Suitable lightweight aggregate has become very expensive.

Some standardization of breakwater dimensions could lead to lower design and fabrication costs.

Those breakwaters where the freeboard is more than 1 foot should have safety ladders provided at intervals of about 150 feet to allow a person to climb onto the breakwater unassisted.

Navigation or radar targets should be placed at more frequent intervals than those required by U.S. Coast Guard regulations. The floating breakwater is difficult to see under dark, stormy conditions.

Some designers strongly prefer chain or chain-nylon line anchor lines over cable, which is likely to be more vulnerable to corrosion.

Quality control in fabrication is very important to ensure adequate coverage of reinforcement and strict adherence to dimensions so the units will float with uniform and specified freeboard.

Neither of the installations at Sitka or Tenakee Springs has experienced any icing of consequence. The Puget Sound sites are ice-free.

Water quality problems that could arise in a small-craft harbor enclosed by an impermeable barrier are avoided by the floating breakwaters. In many cases, the floating breakwater and anchor lines enhance or provide additional habitat.

Some designs for the concrete caisson breakwater have proposed a hollow structure, thus eliminating the cost of the usual Styrofoam core, and then relying on the integrity of the concrete shell and inspections to avoid loss of buoyancy through leakage. The foam core provides a good form for casting and also allows the box to be formed by a continuous pour. However, care must be exercised to assure that the foam does not compress during the pouring operations, thereby altering the design freeboard levels. It is suggested that fabricators be allowed the option of which method is the most economical, or that close cost comparisons be made before a design is fixed. The foam core is good insurance against flooding.

Richey, Eugene P.
Floating breakwater field experience, west coast / by Eugene P. Richey.--Fort Belvoir, Va. : U.S. Army, Corps of Engineers, Coastal Engineering Research Center ; Springfield, Va. : available from NTIS, 1982.
[64] p. : ill. ; 28 cm.--(Miscellaneous report / Coastal Engineering Research Center; no. 82-5). Cover title.
"July 1982."
Report evaluates 11 floating breakwaters located in the Pacific Northwest to provide needed field information on the construction and subsequent performance of these structures. A description of each site and breakwater structure, a discussion of the breakwater's performance based on site inspections and discussions with owners, marina operators, etc., and a set of conclusions are presented.
1. Floating breakwaters. 2. Breakwaters design and construction. I. Title. II. Coastal Engineering Research Center (U.S.). III. Series: Miscellaneous report (Coastal Engineering Research Center (U.S.)); no. 82-5.
TC203 .U581mr no. 82-5 627

Richey, Eugene P.
Floating breakwater field experience, west coast / by Eugene P. Richey.--Fort Belvoir, Va. : U.S. Army, Corps of Engineers, Coastal Engineering Research Center ; Springfield, Va. : available from NTIS, 1982.
[64] p. : ill. ; 28 cm.--(Miscellaneous report / Coastal Engineering Research Center; no. 82-5). Cover title.
"July 1982."
Report evaluates 11 floating breakwaters located in the Pacific Northwest to provide needed field information on the construction and subsequent performance of these structures. A description of each site and breakwater structure, a discussion of the breakwater's performance based on site inspections and discussions with owners, marina operators, etc., and a set of conclusions are presented.
1. Floating breakwaters. 2. Breakwaters design and construction. I. Title. II. Coastal Engineering Research Center (U.S.). III. Series: Miscellaneous report (Coastal Engineering Research Center (U.S.)); no. 82-5.
TC203 .U581mr no. 82-5 627

Richey, Eugene P.
Floating breakwater field experience, west coast / by Eugene P. Richey.--Fort Belvoir, Va. : U.S. Army, Corps of Engineers, Coastal Engineering Research Center ; Springfield, Va. : available from NTIS, 1982.
[64] p. : ill. ; 28 cm.--(Miscellaneous report / Coastal Engineering Research Center; no. 82-5). Cover title.
"July 1982."
Report evaluates 11 floating breakwaters located in the Pacific Northwest to provide needed field information on the construction and subsequent performance of these structures. A description of each site and breakwater structure, a discussion of the breakwater's performance based on site inspections and discussions with owners, marina operators, etc., and a set of conclusions are presented.
1. Floating breakwaters. 2. Breakwaters design and construction. I. Title. II. Coastal Engineering Research Center (U.S.). III. Series: Miscellaneous report (Coastal Engineering Research Center (U.S.)); no. 82-5.
TC203 .U581mr no. 82-5 627

Richey, Eugene P.
Floating breakwater field experience, west coast / by Eugene P. Richey.--Fort Belvoir, Va. : U.S. Army, Corps of Engineers, Coastal Engineering Research Center ; Springfield, Va. : available from NTIS, 1982.
[64] p. : ill. ; 28 cm.--(Miscellaneous report / Coastal Engineering Research Center; no. 82-5). Cover title.
"July 1982."
Report evaluates 11 floating breakwaters located in the Pacific Northwest to provide needed field information on the construction and subsequent performance of these structures. A description of each site and breakwater structure, a discussion of the breakwater's performance based on site inspections and discussions with owners, marina operators, etc., and a set of conclusions are presented.
1. Floating breakwaters. 2. Breakwaters design and construction. I. Title. II. Coastal Engineering Research Center (U.S.). III. Series: Miscellaneous report (Coastal Engineering Research Center (U.S.)); no. 82-5.
TC203 .U581mr no. 82-5 627